A

RUDIMENTARY TREATISE

ON

WARMING AND VENTILATION

BEING A CONCISE EXPOSITION OF THE

GENERAL PRINCIPLES OF THE ART

OF

WARMING AND VENTILATING DOMESTIC AND PUBLIC BUILDINGS, MINES, LIGHTHOUSES, SHIPS, &c.

BY

CHARLES TOMLINSON.

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WARMING & VENTILATION.

INTRODUCTION.

ON THE PHYSICAL AND CHEMICAL PRINCIPLES CONCERNED IN THE ART OF WARMING AND VENTILATION.

AN inquiry into the constitution and uses of our atmosphere in the economy of nature and art, is calculated to promote a solemn feeling of admiration and gratitude. This wonderful creation encloses within its capacious curves, like a vast dome, the widely extended kingdoms of nature, to which it ministers materials for growth, health, and enjoyment, and by its transparency reveals to intelligent beings a glimpse of other creations beyond its limits. At one time, it stands in simple grandeur as a vault of tender blue, displaying the glorious sun and the landscape smiling beneath; at another time, its surface is chequered with fleecy clouds,—"the beauteous semblance of a flock at rest,"—or alpine heights of more than silvery brightness, or huge piled up masses, dark and frowning; all contributing to form wondrous variety and beauty in the aerial scenery, and giving to the landscape below the ever varying charms of light and shade. Again, the blue of this splendid ceiling becomes deeper and deeper, and bright golden points shine out here and there, increasing in number until the whole surface appears as if richly studded with gems.

If these great and glorious sights were of rare occurrence, or could only be witnessed from a few chosen spots on the earth's surface, they would stimulate our curiosity, and we should eagerly hasten to those spots, or read the descriptions and gaze at the pictures which travellers and artists had pre-

pared for us. Their common occurrence, however, causes them to be viewed with indifference; but there are also many hidden wonders connected with the atmosphere equal in beauty to those which appeal directly to the eye, but requiring study for their due appreciation. The atmosphere is a scene of incessant restless activity. The heat of the tropical sun upon the earth sets the air in motion, rarefies and causes it to ascend; meanwhile the air from cooler regions rushes towards the equator to supply the vacuum, performing various useful offices on its way. Here it is the trade wind or the monsoon; there it is the sea or the land breeze; in a third place, it is the hill and valley breeze, all giving health and refreshment to places which otherwise might be uninhabitable. Meanwhile the heated ascending air of the equator proceeds on its useful mission in the direction of the poles, forming an upper current, descending in some places and mitigating the cold of temperate regions, as the under current tempers the heat of tropical climes. The heat, too, which gives force and activity to these aerial currents or vast natural ventilators, also raises the waters of the ocean and charges the air with moisture; this moisture ascends and forms clouds, those busy and active water-carriers which traverse the unobstructed regions of the sky, and pour down their treasures on the city and the plain, and on the desert where no water is, filling the mountain cisterns, whence gush out the springs and rivers; and these descend in a meandering course, and diffuse beauty and blessing on the lower lands long after the rain cloud has been dissolved. It is the resistance of the atmosphere that causes the rain to come down in gentle drops, and thus gradually to diffuse its refreshing influence, instead of falling in torrents and cataracts, as it otherwise would, without the retarding and separating influence of the air. It is the atmosphere which dispenses the white fleecy flakes of snow to the temperate regions, whereby the earth is covered and protected from the chilling influence of a low temperature; the air, too, is the region of mists and fogs,

which bring moisture in a still more gradual manner; a cold current of air blowing over a warmer stratum of air, and cooling it, thereby rendering its moisture visible; or, after sun-set, the river may be warmer than the air, and the escaping vapour condense into large rolling masses. But we especially notice the beneficial effects of differences of temperature between the air and the earth in the formation of dew; the moisture which the heat of the day had exhaled from the earth is deposited when a cloudless sky allows the earth to radiate its heat into space, and to cool down below the temperature of the air; the refreshing moisture is then condensed upon vegetation and upon surfaces where it is most needed.

Not only are we able to trace in the atmosphere those great and regular motions which bring about an interchange between the air of the equator and that of either pole, but there are other motions, apparently more fitful and irregular, in the winds, which blow from all points of the compass, and tend perpetually to restore the equilibrium of heat and moisture.

How wonderful, too, is the action of the atmosphere on light. By its means the sun's rays are diffused, and their influence extended from the sunshine to the shade. Were it not for the atmosphere, the sun would shine in an intensely dark sky, and no object would be visible unless the solar rays fell directly upon it. Sun-set would be a sudden transition from light to darkness; and sun-rise a painful change from intense darkness to intense light. But under the present wise and providential arrangement, the transition from day to night is calm and peaceful; the sun departs in splendour, like a monarch attended by a gorgeous court, leaving a mild and subdued scene of beauty behind; the soothing influences of evening gradually steal upon us, and new scenes of wonder and beauty gradually become unfolded. After some hours of peace and rest, the portals of the eastern sky slowly open, and one rosy messenger after another ascends to announce the advent of the king of day.

In addition to these complicated duties which the atmosphere has to perform, there are yet others still more wonderful. A large number of the operations of nature are, as it were, daguerreotyped in the air in such a manner, as to convey to sentient and intelligent creatures information of what is going on. The murmuring of waters, the tinkling of rills, the whispering of winds, the sound of the forest in the blast, the rush of the cascade, the roar of the ocean, and the roll of the thunder, are only certain motions among material bodies, which impress their own peculiar characters on the air, and form what are called *sounds*. Sounds are of so numerous and, at the same time, of so distinctive a character, that a large portion of every language is appropriated to their precise description. Thus, to define a few of the sounds emitted by certain animals, we speak of the lowing of cattle, the bleating of sheep, the cawing of rooks, the cooing of pigeons, the hissing of snakes, and many others. These sounds, expressive of certain wants and motions, feelings and sympathies, have, doubtless, an intelligent meaning among the respective species of animals to which they apply; but both sound and its perception are alike dependent on the atmosphere. The phenomena of sound and of hearing, however, obtain their most perfect and exalted development in articulate speech, by which intelligent and responsible creatures are enabled to shape air into words, those swift and winged messengers by which we express our wants and feelings, by which we advise, instruct, or admonish others, share in their joys, their sorrows and affections; a glorious and also a fearful gift, since every idle word that man shall speak he will have to give account of at the day of judgment. Inferior only to articulate speech is the language of music, which, like the beauty produced by form and colour, is an invention calculated to promote the happiness of man.

The uses of the air in the arts of life are innumerable. It is the cheapest and most effectual prime mover; we have merely to supply the tools, the machinery, and the work to be

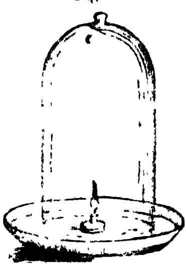
done, and it will labour with untiring activity. It wafts our ships over every sea, turns our mills, raises water in our pumps, accompanies the diver in the diving bell, bears up the balloon, feeds our furnaces; but here we come to a distinct series of valuable offices performed by the atmosphere, if possible, even more extensive and important than those already referred to. The chemical history of the atmosphere is even more wonderful than the physical,* and will now require, for the object of the present essay, a few details.

The atmosphere is composed essentially of two gases, in a state of mechanical mixture, named oxygen and nitrogen. In its pure state, oxygen is chiefly remarkable for its energetic properties in promoting combustion, decomposition, and various chemical changes. A taper, with a mere spark of fire in the wick, will, when plunged into oxygen, burst into flame and burn brilliantly; iron wire, made red-hot at one extremity, will burn away with the greatest ease in this gas. An animal, in an atmosphere of pure oxygen, suffers from excess of vital action; its pulses throb with increased rapidity and vigour, the vital spark, as it were, bursts into flame, and destroys the animal. Nitrogen (or, as it is sometimes called, *azote*,) is as inert in its properties as oxygen is active. It supports neither life nor combustion, and its principal use in the atmosphere seems to be to dilute the oxygen, and to subdue the wonderful energy of this vigorous element to the endless number of useful purposes which it has to perform in the economy of nature. The proportions in which these two gaseous bodies are mingled, are very unequal; every atom or particle of oxygen in the atmosphere is accompanied by four atoms or particles of nitrogen; or, in other words, if we take a measure of any capacity, divided into five equal parts, and decant into it four parts of nitrogen and one part of oxygen, we get a mixture identical in all respects with pure atmospheric air.

* The physical properties of the atmosphere are investigated in *Rudimentary Pneumatics*.

In the great chemical operations of nature which are dependent on the atmosphere, oxygen passes through various mutations, and enters into new combinations, which form the basis of grand and wonderful contrivances. Some of the most important of these operations depend on the process of combustion, of which the following is a simple illustration:—

Fig. 1.



A piece of wax taper (Fig. 1), fixed in the centre of a cork, is lighted and floated on the surface of water in a shallow dish; if this be enclosed within a bell glass, the mouth of which dips into the water and rests on the dish, the air of the glass will be cut off from any communication with the external atmosphere. The flame of the taper will immediately diminish, and in a few seconds be extinguished. On examining the air left in the glass, it will be found incapable of supporting animal life or combustion; four-fifths of the original bulk of air is still nitrogen, and this is apparently unchanged; the remaining fifth is no longer oxygen, but a compound of oxygen with the carbon and hydrogen of the flame—oxygen and carbon producing carbonic acid, and oxygen and hydrogen producing water, which, in the form of vapour, condenses on the inner surface of the glass.

Now the product of combustion, called carbonic acid, is incapable of supporting life and combustion, and thus resembles nitrogen. But there are these differences between them:—nitrogen is a little lighter than its own bulk of atmospheric air; carbonic acid is considerably heavier; nitrogen is an elementary or simple substance, that is, one which has never yet been resolved into two or more dissimilar parts; carbonic acid, on the contrary, is a compound capable of being separated or decomposed into carbon or charcoal, and oxygen. Moreover, pure nitrogen, shaken up in a bottle, with a little lime water, produces no effect; carbonic acid renders it turbid, by combining with the lime and rendering it insoluble; nitro-

gen is scarcely absorbed by water, but water absorbs its own volume of carbonic acid; nitrogen has no taste or smell, carbonic acid has a sharp taste and an acid reaction. Hence, it will be seen, that these two bodies, which have the common property of extinguishing life and preventing combustion, are marked by characteristic differences.

Some idea may be formed of the enormous demands on the oxygen of the atmosphere for supporting combustion, from the fact, that a single iron furnace burns or consumes, in the course of twenty-four hours, not less than three hundred and ten tons weight of atmospheric air, or as much as would be required for the respiration of two hundred thousand human beings within the same period.

Carbon, which forms the solid basis of most fuel, and in a minutely divided state renders flame luminous, is a simple substance, and exists in nature under a variety of forms. Its purest form is the diamond, as is proved by the formation of carbonic acid only, when it is burnt in pure oxygen. Charcoal and coke are other well known forms of carbon, the one obtained from wood and the other from coal; coal is a compound of carbon, hydrogen, nitrogen, and oxygen, with a mineral and earthy residue. Wax, tallow, &c., are compounds of carbon, hydrogen, and oxygen.

Hydrogen, which is the source of all common flame, is the lightest substance that has ever been weighed: it is more than fourteen times lighter than its own bulk of atmospheric air at the same temperature; it supports neither life nor combustion. A lighted taper plunged into it is extinguished, but the hydrogen itself takes fire and burns at the mouth of the jar, where it is in contact with the oxygen of the air, with which it unites and forms water. One volume of oxygen combines with two of hydrogen to form water; or by weight, one grain of hydrogen unites with eight grains of oxygen, and as the hydrogen is sixteen times lighter than its own bulk of oxygen, it follows that one grain of hydrogen will occupy twice the bulk of eight grains of oxygen. Pure hydrogen burns with scarcely any light;

in the flame of our lamps, candles, gas lights, &c., the minutely divided carbon, in rising up through the flame, becomes white hot, and presents innumerable luminous points; at the exterior of the flame the oxygen of the atmosphere seizes the minute atoms of carbon as they escape, and, by combining with them, forms invisible carbonic acid. A cold substance, such as a piece of glass or metal, held in a flame for a moment will condense a portion of the carbon in a minutely divided state If a lamp have a deficient supply of air, it will smoke, that is, a portion of the carbon of the flame will escape without combining with the oxygen of the air. Lamp black is formed by burning oil in a close chamber with a deficient supply of air.

Hydrogen unites with nitrogen to form ammonia, three volumes of hydrogen being required to one of nitrogen. This substance is pungent and acrid, but when diluted with air is an agreeable stimulent. It is very soluble in water, which at the temperature 50°, takes up 670 times its bulk of the gas. Ammonia is an alkali, and combines readily with acids, producing an important class of ammoniacal salts.

Nitrogen and oxygen combine to form nitric acid, one part of nitrogen uniting with five parts of oxygen. Not only are these numbers different from those which represent the composition of the atmosphere, but the mode of combination is different. The oxygen and nitrogen of the atmosphere are mixed mechanically, just as a portion of fine sand diffused through water may be said to mix with it without combining. In either case, the bodies preserve their own peculiar properties; or the properties of the compound form a mean between those of its component elements. But in a chemical combination between two bodies, a third body is formed, whose properties need not, and seldom do, resemble those of the component elements. Thus sulphur and oxygen combine chemically to produce sulphurous or sulphuric acid, substances whose properties are quite different from those of the sulphur and oxygen which produce them; the sulphurous has also very different properties from the sulphuric. So with nitric acid,

this compound has none of the properties of the constituents of the atmosphere, but a new set of properties peculiar to itself This powerful acid may be formed artificially in various ways but only one need here be mentioned. By passing a succession of electric sparks through a mixture of oxygen and nitrogen, this acid is formed; so also, during a thunder storm, the lightning striking through vast masses of atmospheric air, produces nitric acid, which, combining with ammonia, also formed in the atmosphere, descends with the rain upon the earth in the form of nitrate of ammonia.

Now the object for which these details have been brought forward, is to enable the reader to take an enlarged view of the process of combustion, for this, in fact, constitutes the chief means by which nature accomplishes her annual cycle. An accurate knowledge of the homely processes of warming and ventilation depends upon a clear insight into the principles of combustion, and it is only an oft repeated truism, that our useful arts become more efficient in practice, more economical, and more conducive to our happiness, in proportion to our knowledge of the principles upon which they depend. Now, according to the common acceptation of the term, combustion is the rapid union of a combustible with a supporter of combustion, whereby new compounds are formed, heat and light accompanying the formation. Thus a piece of iron wire or of phosphorus ignited and plunged into a jar of oxygen gas burns vividly, the iron falling in molten drops amid showers of scintillations, and the phosphorus emitting a vivid flood of painful light. In this process, the oxygen and the iron unite to form a new substance, oxide of iron; the oxygen and the phosphorus also form a new substance, phosphorous acid. If, however, the iron be exposed long enough to the atmosphere, the oxygen will combine with it in precisely the same manner, and form oxide of iron; months or even years may be required for the completion of the process which in the jar of oxygen was accomplished in a few seconds; but the result is the same. The same amount of heat is evolved by the combination of the

oxygen and the iron during the slow process of rusting, as in the rapid process of burning. So also with the phosphorus. A piece of this substance exposed to the air combines with the same amount of oxygen, and evolves precisely as much heat during the time that it slowly wastes away, and produces the same weight of acid as it would do if burnt in a jar of oxygen.

Now it must be evident, that if a process, rapidly brought about in one case and slowly in another, produce the same results, we do not add to our knowledge by associating different names and different trains of thought with the one as compared with the other; on the contrary, we disembarrass the subject by considering the processes as identical; whether the combustion be rapid or slow, it is still combustion. Undoubtedly there are cases where slow combustion is not possible. A piece of coal and the oxygen necessary to its combustion may remain in contact for centuries without undergoing any change; but the moment a spark of fire is introduced, they begin to combine and soon disappear, with all the more obvious phenomena of combustion. In such a case, all we can say is, that a high temperature is necessary for the combination; but this case does not disturb the view we are endeavouring to impress upon the reader, that combustion may be a very slow process as well as a very rapid one.

Let us take another case of combustion. If a portion of the solid food of animals be placed in a red hot platinum crucible, it will burn away; its carbon will unite with oxygen from the air and form carbonic acid; its hydrogen will unite with oxygen from the air and form water; its nitrogen may escape free, or it may unite with a portion of its hydrogen, and form ammonia; and in this way all the gaseous volatile products will be expelled from the crucible, leaving behind only a small portion of ash, which consists of salts, some of which are soluble in water and others insoluble in that fluid.

Now, in a chemical point of view, the living animal frame is a real apparatus for combustion; it is a vital furnace, in which the carbon supplied by the fuel, which we call *food*,

is burnt, and, combining with oxygen, escapes by the lungs and the skin into the atmosphere, under the form of carbonic acid. In this apparatus also the hydrogen of food is burnt, and uniting with oxygen, escapes as aqueous vapour; the nitrogen of the air, as taken into the lungs, is again exhaled by respiration, but the nitrogen and soluble mineral portions of the food are rejected under the form of oxide of ammonium in the urine; the insoluble mineral portions of the food are rejected in the form of solid excrement.

Now every portion of food which a person of mature age takes into his system, is thus dispersed from day to day. In infancy and youth a portion is retained to form materials for growth; in old age, the individual loses more than he receives, and, consequently, wastes slowly away. But, in each case, the natural process is similar to the artificial one represented in the heated platinum crucible. We cannot, therefore, resist the evidence that the combustion of food, whether in the animal or in the crucible, is one and the same process; the only difference being, that in the crucible the heat is intense and the process rapid; in the animal, the heat is moderate and the process comparatively slow. That which is called animal heat (98° Fahr.), is in fact the heat of combustion, and the object of the domestic processes of warming and ventilation is to enable the animal to maintain this heat, and to convey away the gaseous products of combustion as fast as they are formed. The soluble and insoluble products of combustion are conveyed away by other natural means; and it will be our duty hereafter to show, that it is as unwise to neglect the means for clearing off our gaseous excrements, as it would be insane and unnatural to attempt to retain those of another kind.

Another proof of the identity of the two processes is that nature disposes of the products of combustion in precisely the same manner, whether derived from ordinary combustion or animal respiration. The vegetable kingdom is the grand laboratory wherein these products of combustion are decom-

posed and elaborated into new combinations. Plants inhale or absorb carbonic acid, decompose it, retain the carbon as materials for growth, and return the oxygen back to the atmosphere; plants absorb water, or aqueous vapour, decompose it, retain its hydrogen, and also return back the oxygen to the atmosphere; plants sometimes take nitrogen directly from the air, and sometimes indirectly from the oxide of ammonium or from nitric acid. Thus it will be seen that the chemical function of plants is directly the reverse of that of animals—the animal kingdom constituting an immense apparatus for combustion; the vegetable kingdom an equally grand apparatus for reduction, in which reduced carbonic acid yields carbon, reduced water its hydrogen, and in which also reduced oxide of ammonium and nitric acid yield their ammonia or their nitrogen. The organic matter which constitutes the food of animals is destroyed by them, and rendered for the most part inorganic; this, in its turn, becomes the aliment of plants, the materials with which plants elaborate organic compounds, the atmosphere serving as the means of communication between the two kingdoms. Organic vegetable substances pass ready formed into herbivorous animals, which destroy a portion of them, and appropriate the remainder as materials for growth. From herbivorous animals these organic matters pass ready formed into the carnivorous, who destroy or retain some of them, according to their wants. The herbivorous animals are slaughtered for the use of the carnivorous, and when these, in their turn, cease to live, they decompose, and the atmosphere again takes up, in various ways and by various processes, the materials of which they were composed.

The great stimulus which gives motion to the wonderful machinery of the vegetable world is solar light. Under its influence, the carbonic acid yields its carbon, the water its hydrogen, the ammonia its nitrogen. It is not for the purpose of purifying the air that plants are especially necessary to animals. Their great use is to furnish a never failing supply of organic matter, ready prepared for assimilation, in short,

with fuel, which animals can burn for their own use. The purification of the air by vegetation is a remote service; the other service is so immediate, that if it were to fail us during a single year, the earth would be depopulated.* The mean amount of carbonic acid in the atmosphere is scarcely one volume in 2,000, which is a surprisingly small quantity, when we consider how numerous and productive are the sources of this gas. Volcanoes, fires, animals, fermentation, and decay, are constantly producing it, nor will the quantity given off by a single individual appear insignificant, when it is stated that Sir Humphry Davy found that he required, for the purposes of respiration, during the 24 hours, 45,504 cubic inches of oxygen, weighing 15,751 grains, and producing 31,680 cubic inches of carbonic acid, weighing 17,811 grains, or 4,853 grains of carbon. These numbers vary with different individuals, and also in the same individual at different periods of the day; according to Dr. Prout, the maximum quantity of carbonic acid is given off about noon, up to which period it gradually increases from the beginning of twilight; and after noon, it as gradually diminishes until evening, and is at its minimum during the night. It appears, from the mean of a large number of observations, that the average quantity of carbon evolved from the lungs amounts to 130 grains per hour, or 3,120 grains in 24 hours, which is rather more than 7 ounces daily. This calculation does not take into account the carbonic acid evolved by cutaneous respiration. The quantity of oxygen consumed in respiration varies also with the state of exertion or repose of the individual. According to an observation of Lavoisier, the consumption of oxygen in the two states was as 32 to 14. The

* The chemical relations between the three great kingdoms of nature are stated at greater length in our *Essay on the Application of Chemistry to Agriculture*, appended to Professor Fownes' *Rudimentary Chemistry*; but the reader who desires to pursue the subject further, is referred to Liebig's *Chemistry in its Application to Agriculture*, Professor Johnstone's *Elements of Agricultural Chemistry and Geology*, and also to a Lecture by M. Dumas, on the *Chemical Statics of Organized Beings*.

quantity of vapour given off by the lungs has also been variously stated, but the average is supposed to be about 3 grains per minute; according to Thenard, the amount of vapour given off by the skin varies from 9 to 26 grains per minute.

In the process of respiration, a full grown man draws into his chest about 20 cubic inches of air; only one-fifth of this is oxygen, and nearly one half of this oxygen is converted into carbonic acid. Now allowing fifteen inspirations per minute for a man, he will vitiate about 300 cubic inches, or nearly one-sixth of a cubic foot of atmospheric air, and this, by mingling as it escapes with several times as much, renders at least two cubic feet of air unfit for respiration. Now the removal of this impure air, and the bringing in of a constant fresh supply, have been provided for by nature in the most perfect manner, and it is by our ill-contrived artificial arrangements that the provision is defeated. The expired and vitiated air, as it leaves the chest, is heated to very near the temperature of the body, viz. 98°, and being expanded by the heat, is specifically lighter than the surrounding air at any ordinary temperature; it therefore ascends and escapes to a higher level, by the colder air pushing it up, as it does a balloon. The place of this heated air is constantly supplied by the colder and denser air closing in on all sides. In the open air the process is perfect, because there is nothing to prevent the escape of the vitiated air; but in a close apartment, the hot air, rising up to the ceiling, is prevented from escaping; and gradually accumulating and becoming cooler, it descends and mingles with the fresh air, which occupies the lower level. We thus have to inhale an atmosphere which every moment becomes more and more impure and unfit for respiration; and the impurities become increased much more rapidly by night when lamps and candles or gas are burning, for flame is a rapid consumer of oxygen. Under these circumstances, our only chance of escape from suffocation is in the defective workmanship of the house-carpenter; the crevices in the window frames and doors allow the foul air a partial

exit, as may be proved by holding the flame of a candle near the top of a closed door, in a hot room; it will be seen that the flame is powerfully drawn towards the door in the direction of the outgoing current; and on holding the flame near the bottom of the door, it will be blown away from the door, shewing the direction of the entering current. If we stop up these crevices, by putting list round the windows and doors, so as to make them fit accurately, we only increase the evil. The first effect is, that the fire will not *draw* for want of sufficient draught; if the inmates can put up with a dull fire and a smoky atmosphere, they soon become restless and uncomfortable—young people get fretful and peevish, their elders irritable, respiration becomes impeded, a tight band appears to be drawn round the forehead, which some invisible hand seems to be drawing tighter and tighter every moment; the eyeballs ache and throb, a sense of languor succeeds to fits of restless impatience, yawning becomes general, for yawning is nothing more than an effort of nature to get more air into the lungs; under these circumstances the announcement of tea is a welcome sound, the opening and shutting of the door necessary to its preparation give a vent to the foul air, the stimulus of the meal mitigates the suffering for a time, but before the hour of rest, the same causes of discomfort have been again in active operation, and the family party retires for the night indisposed and out of humour.

But in the bed room, the inmates are not free from the malignant influence. The closed doors, the curtained bed, and the well closed windows, are sentinels which jealously guard against the approach of fresh air. The unconscious sleepers at each respiration vitiate a portion of air which, in obedience to the law of nature rises to the ceiling, and would escape, if the means of escape were provided; but, in the absence of this, it soon shakes off those aerial wings, which would have carried it away, and becoming cooler and denser, it descends, and again enters the lungs of the sleepers, who unconsciously inhale the poison. When the room has become surcharged

with foul air, so that a portion must escape, then, and not till then, does it begin to escape up the chimney. Hence many persons very properly object to sleep in a room which is unprovided with a chimney; but it is evident that such a ventilator is situated too low down to be of much service. If there be no chimney in the room, a portion of the foul air escapes by forcing its way out of some of the cracks and crevices which serve to admit the fresh air.

That this sketch is not overdrawn, must be evident to any one who, after an early morning's walk, may have returned directly from the fresh morning air into the bed room which he had left closely shut up an hour before. What is more disgusting than the odour of a bed room in the morning? Why is it that so many persons get up without feeling refreshment from their sleep? Why do so many persons pass sleepless nights? The answer to these and many other similar questions may be frequently found in defective ventilation. How much disease and misery arises from this cause it would be difficult to state with any approach to accuracy, because the causes of misery are very complicated. Among the poor, the want of sufficient nourishment, neglect of temperance and cleanliness, and excessive labour, all act with aggravating effect upon want of ventilation and drainage. Among the middle classes, mental anxiety, overtasked powers, insufficient out-door exercise, are also aggravating causes; but there is a similar want of attention to ventilation and drainage. The rich suffer least, because they pass much of their time in the pure air of the country, and are relieved from a good deal of anxiety, by being independent in circumstances; their rooms are also larger and less crowded than those of the other classes; but still there is a neglect of ventilation, and they often breathe a poisonous atmosphere for hours together in the crowded and heated ball room, the theatre, and the fashionable assembly; so that fainting, headache and sickness, are the not uncommon results.

A poisonous atmosphere! The expression will not be found too strong when we examine the ingredients of the air of an

unventilated room. The products of combustion, whether they be those of the respiration of human beings, or the burning of artificial light, consist of—1, carbonic acid; 2, nitrogen; 3, vapour of water, mingled with various animal products of a very offensive nature. Gas also often contains a minute portion of sulphuretted hydrogen which escapes, and a minute portion of the gas itself (carburetted hydrogen) also escapes unburnt.

Carbonic acid gas is a deadly poison. If we attempt to inhale it by putting the face over the edge of a beer vat, the nostrils and throat are irritated so strongly, that the glottis closes, and inspiration becomes impossible. In its pure state, then, it is impossible to breathe carbonic acid gas; but when this gas is largely diluted with air, it can be breathed, and the symptoms resemble those of apoplexy. Professor Christison quotes a case related by M. Chomel of Paris, of a labourer, who was suddenly let down to the bottom of a well containing carbonic acid diluted with air, where he remained three-quarters of an hour. On being drawn up, he was first affected with violent and irregular convulsions of the whole body, accompanied by perfect insensibility; fits of spasm, like tetanus, then came on. During the second day, these symptoms went off, and he continued afterwards to be affected with dumbness. It is especially to be noted, that contrary to general popular belief, these effects may be produced in situations where the air is not sufficiently impure to extinguish the flame of a candle; nor does the lurking danger display itself to the sense of taste or of smell.

The danger of using charcoal as a fuel will be noticed further on; but we may here remark, that the proportion of carbonic acid necessary to produce a poisonous atmosphere is very small; so much so, that in attempts at suicide by burning charcoal in an open room, the people who have entered the apartment have found the air quite respirable, and the choffer burning, although the person they sought was in a state of deep coma, from having been long exposed to the noxious influence.

Now as no person would consent habitually to swallow a small portion of liquid poison, knowing it to be such, though diluted with a very large portion of pure water, so it is equally unwise to consent habitually to inhale a small portion of gaseous poison, knowing it to be such, though diluted with a very large portion of pure air; and yet this is what the majority of persons actually do who occupy apartments unprovided with proper ventilating apparatus.

Nitrogen gas, which constitutes four-fifths of our atmosphere, is not, like carbonic acid gas, a poison. Its properties are altogether inert; it will not support respiration nor combustion, simply from the absence of oxygen. An animal plunged into an atmosphere of nitrogen would die, simply because this gas is incapable of oxygenising the blood. A flame is extinguished in this gas, simply because there is no affinity between it and the incandescent hydrogen and carbon.

The vapour given off by the lungs and the skin is charged with offensive animal effluvia, which greatly promote the contamination of the air of a crowded apartment. Dr. Faraday expressed his opinion to a parliamentary committee in 1835, on the subject of ventilation, that—"Air feels unpleasant in the breathing cavities, including the mouth and nostrils, not merely from the absence of oxygen, the presence of carbonic acid, or the elevation of temperature, but from other causes, depending on matters which are communicated to it by the human being. I think that an individual may find a decided difference in his feelings when making part of a large company, from what he does when one of a small number of persons, and yet the thermometer give the same indication. When I am one of a large number of persons, I feel an oppressive sensation of closeness, notwithstanding the temperature may be about 60° or 65°, which I do not feel in a small company at the same temperature, and which I cannot refer altogether to the absorption of oxygen, or the evolution of carbonic acid, and probably depends upon the effluvia from the many present; but with me, it is much diminished by a lowering of the tem-

perature, and the sensations become much more like those occurring in a small company. The object of a good system of ventilation is to remove the effects of such air."

The effects of air, vitiated by animal effluvia, is evident in the diseases of the lower animals when crowded together in confined places. The glanders of horses, the pip of fowls, and a peculiar disease in sheep, all arise from this cause; and it is stated that, for some years past, the English nation has been saved £10,000 a year, in consequence of the army veterinary surgeons adopting a simple plan for the ventilation of the cavalry stables.

Our systems of artificial illumination have even a greater deteriorating effect upon the air of an apartment than the respiration of human beings. The leakage of a gas pipe, or the imperfect combustion of the gas itself, in an apartment, would cause the inmates to inhale a portion of the gas. Sir Humphry Davy found, that when he breathed a mixture of two parts air and three of carburetted hydrogen, he was attacked with giddiness, headache, and transient weakness of the limbs; but common gas is often contaminated with sulphuretted hydrogen, as the blackening of the white painted wainscoting of rooms proves, in spite of the purifying processes adopted at the gas works. This gas is the most deleterious of all the aerial poisons. It has been found by experiment, that air, impregnated with a 1,500th part of the gas, kills a bird in a short space of time; and that with about twice that proportion, or an 800th, it will soon kill a dog. This gas is emitted by cesspools and sewers, and has been a frequent cause of death when breathed in a state of concentration. "The individual becomes suddenly weak and insensible, falls down, and either expires immediately, or if he is fortunate enough to be quickly extricated, he may revive in no long time, the belly remaining tense and full for an hour or upwards, and recovery being preceded by vomiting and hawking of bloody froth." When the noxious emanations are less concentrated, the symptoms are still very alarming; and in the dilute form,

as in the emanations from the gully holes of the sewers of London, persons inhaling them have often been attacked with sickness, colic, imperfectly defined pains in the chest, and lethargy.

The emanations arising from the imperfect or slow combustion of oil and tallow are most injurious to health. The vapour of a smoky lamp, if disengaged in small quantities, excites intense head-ache. The fumes of the burning snuff of a candle are probably of the same nature, and are very poisonous, and every one must have remarked their penetrating nature; they fill the room the moment a candle is blown out, and their disgusting odour pervades the whole house in a a very short time. Dr. Christison quotes a case in which they proved fatal; a party of ironsmiths, who were carousing on a festival day at Leipzig, amused themselves with plaguing a boy, who was asleep in a corner of the room, by holding under his nose the smoke of a candle just extinguished; at first he was roused a little each time, but when the amusement had been continued for half an hour, he began to breathe laboriously, was then attacked with incessant epileptic convulsions, and died on the third day.

In addition to all these contaminating agents, carbonic acid, nitrogen, animal effluvia, carburetted and sulphuretted hydrogen, &c., to which the air of an unventilated apartment is liable, there is yet another cause of injury to health in the disturbed electrical condition of vitiated air. This is a subject on which science has hitherto thrown no light. All that we can do is to record the fact, that pure air, such as is fit for respiration, is *positively* electric, while the air, which has become impure, and consequently unfit for respiration, is *negatively* electric.

The effects of breathing an impure air have frequently been insisted upon by medical and other writers. In the evidence taken before the Committee of the House of Commons, on the health of towns, in the year 1840, the medical witnesses stated, that scrofulous diseases were a common result of bad ventila-

tion,* and that, in the case of silk weavers, who pass their lives in a more close and confined air than almost any other class of persons, their children are peculiarly subject to scrofula, and softening of the bones. Dr. Arnott stated, that an individual, the offspring of persons successively living in bad air, will have a constitution decidedly different from a man who is born of a race that has inhabited the country for a long time; that the race would, to a certain extent, continue degenerating. Defective ventilation deadens both the mental and bodily energies, it leaves its mark upon the person, so that we can distinguish the inhabitants of a town from those of the country. This witness, in alluding to the want of knowledge among all classes on the subject of ventilation, states that he had heard at the Zoological Gardens of a class of animals where fifty out of sixty were killed in a month, from putting them into a house which had no opening in it but a few inches in the floor. "It was like putting them under an extinguisher; and this was supposed to be done upon scientific principles."

Some of the details in this report of diseases, consequent on the habitual breathing of air, vitiated by a number of human beings, crowded together in a badly drained and ill-ventilated part of London, are so frightful, that it is impossible to quote them here. No doubt these details refer to extreme cases among the poor and destitute; but no one will contend that the science and legislation of the day should be exerted only

* Mr. Carmichael, in his *Essay on the Nature of Scrofula*, accounts for the extreme prevalence of the disease in the Dublin House of Industry, at the time he wrote (1810), by mentioning that in one ward of moderate height, 60 feet by 18, there were 38 beds, each containing *three* children, or more than 100 in all. The matron remarked, that there is no enduring the air of this apartment when the doors are first thrown open in the morning; and that it is in vain to raise any of the windows, as those children who happened to be inconvenienced by the cold, close them as soon as they have an opportunity. The air they breathe in the day is little better; many are confined to the apartments they sleep in, or crowded to the number of several hundred in the school room.

for those who have influence to command, or means to purchase their aid. Every one who has knowledge or wealth at his disposal, is bound to exert it as much for the benefit of his ignorant and poorer brethren as for his own pleasure and profit. There is not only a moral law requiring us to do so, but there is also a natural law, and both have this distinguishing proof of their divine origin; they are self acting; they confer the reward of obedience, and inflict the penalty of transgression, with a precision and certainty which find no parallel in mere human laws and institutions. The fevers and contagious diseases, arising from our neglect of the poor, find their way into our own dwellings; the miasma of our courts and alleys enters our lungs, and casts us on a bed of sickness. If, through the mercy of God, we are permitted to rise again, ought we not to practise the lesson which the penalty has been seeking to convey to us?

But not only are our dwelling houses badly ventilated, but those buildings on which the architect has lavished all his art and skill are, for the most part, entirely destitute of special means for ventilation; and are so constructed, as to render the application of such means extremely difficult, or even impossible. Such a contrivance seldom enters the mind of the architect. A building capable of holding from 800 to 1000 persons, whether it be a church, a lecture room, an assembly room, or a concert room, is, in consequence of this neglect, the too frequent scene of much painful suffering. When such a room is crowded, and the meeting lasts for some hours, especially in winter, the consequences are sufficiently marked; "either such a multitude must be subjected to all the evils of a contaminated and unwholesome atmosphere, or they must be partially relieved by opening the windows, and allowing a continued stream of cold air to pour down upon the heated bodies of those who are near them, till the latter are thoroughly chilled, and, perhaps, fatal illness is induced; and unfortunately, even at such a price, the relief is only partial, for the windows being all on one side of the room, and not

extending much above half way to the ceiling, complete ventilation is impracticable. This neglect is glaringly the result of ignorance, and could never have happened, had either the architects or their employers known the laws of the human constitution."*

The same intelligent writer remarks, that in churches fainting and hysterics occur more frequently in the afternoon than in the morning, because the air is then at its maximum of vitiation. Indeed, in a crowded church, the effects of deficient air are visible in the expression of the features of every one present—"either a relaxed sallow paleness of the surface, or the hectic flush of fever, is observable, and, as the necessary accompaniment, a sensation of mental and bodily lassitude is felt, which is immediately relieved by getting into the open air." Some persons, however, do not find this relief; the headache often lasts for hours, and ends in a bilious or nervous attack.

Our school rooms are also sadly defective in respect of ventilation, and we have known cases where, with all the windows open, a proper supply of air could not be introduced into the crowded apartment. When the weather did not allow of open windows, the atmosphere of the room was most loathsome to a visitor entering it from the fresh air. All the inmates complained of a sensation of fulness and tightness in the forehead, and headache more or less acute. Command of temper on the part of the teachers, and mental progress on the part of the pupils, are of course next to impossible under such circumstances. The writer would appeal to the experience of teachers in general, whether the slow comprehension and listlessness of children in school, who are sharp and clever in the playground, may not be traceable in a great measure to the vitiated air which they are compelled to inhale?

In curious contrast to the defective arrangements of most of our public buildings, with respect to ventilation, are our public

* Dr. Andrew Combe's *Principles of Physiology.*

theatres. These are, for the most part, tolerably well ventilated, or at least some attempt is made to procure ventilation, and the managers do not fail to parade the fact in their play-bills at the opening of the season. They are practical men; they know that for some years past the attention of the public has been directed to the subject of ventilation, and that a studious attention to the comfort of the house is as likely to bring people to it as attractive performances. They know, too, that people are more likely to enjoy and applaud the business of the stage when they can breathe freely, than when the head is aching and the senses are steeped in the drowsiness of a mephitic atmosphere. Some of the methods of ventilating theatres are clever and efficient, as will be noticed hereafter, and could easily be applied to those far more important buildings, the church and the lecture room.

The traveller, in pursuit of health, business, or pleasure, is everywhere exposed to inconvenience and suffering from want of ventilation. In our coaches, railway carriages, and steam-boats, there are no means, or very inefficient ones, for ventilation. Many of our readers will probably be able to call to mind their nights of suffering in the heavy coaches of twenty years ago, or less. The writer has frequently travelled inside the Salisbury coach in winter, which left London at 5 P.M., and arrived in Salisbury next morning at about 7 A.M., thus performing a journey of 85 miles in 14 hours; such a journey, with six inside (and the writer has sometimes formed one of eight), with windows closed at the special request of some lady or gentleman, who seemed capable of breathing without the usual supply of fresh air, was a protracted torture not to be voluntarily endured in these days.* Yet it must be confessed that our railway carriages are

* In illustration of this part of our subject, we venture to relate the following anecdote, which, as far as we know, has never before appeared in print:—Some years ago, an elderly gentleman, well known in the west of England, was travelling in the night coach from London to Salisbury, when he requested permission to have one of the windows

not much better when the windows are closed and the travellers are numerous. A second class carriage often contains from twenty-four to thirty, and even forty persons, and the air, under such circumstances, is intolerable. The first class carriages are better, because there is less crowding, but even these are seldom provided with efficient means for the escape of the vitiated air. The sleeping cabins of our steam-boats, though fitted up with general attention to comfort, are entirely without any special contrivances for ventilation. We have travelled more than once from London to Hamburg, and have slept, or endeavoured to sleep, two nights in the cabin of one of the steam company's magnificent boats. The eagerness with which we have exchanged the fœtid air of the cabin for the pure air of the deck, even in rainy or boisterous weather, will be understood by all who have undertaken such a voyage. The horrors of the crowded fore-cabin are happily known to the writer only by description.*

down: this was stoutly refused by one of the five other passengers, and an altercation arose, which was suddenly cut short by a young midshipman thrusting his fist through the glass window, and, turning to the supplicant for fresh air, to enquire whether he should break the other also. This was declined: the obstinate traveller sat in silence during the rest of the journey; but the old gentleman, interested by the bold and original conduct of his young friend, invited him to his house, and afterwards became the means of greatly advancing his prospects in life.

* I once took my passage in a steam-boat from Cologne to Rotterdam (at that time a voyage of nearly forty hours), and found, when I had got on board, that there was no sleeping accommodation. This was of no consequence during the day time, and not of much consequence, in fine weather, during the night to an old traveller; but on this occasion, as night advanced, a cold drizzling rain compelled the passengers to seek refuge in the small cabin, the only one the vessel afforded. When tea and supper were fairly over, and nightcaps of various descriptions had been distributed among the guests, the low bench round the cabin was completely occupied; those who could sleep did so; those who could not, tried a variety of postures, looked wistfully at the four comfortable corners occupied by envied sleepers; some had slid down

In our naval and merchant service much disease and mortality are the direct consequences of defective ventilation. The lower decks and close cabins of ships are often crowded with people engaged in cooking, eating, drinking, and sleeping. Their condition is bad enough in fair weather, but in a gale of wind, with the scuttles closed and the hatches fastened down, and no means provided for the admission of fresh air below but what can find its way by an opening of a few feet square; when 'the vitiated effluvia from the healthy, the sick, and

upon the floor; others found a hard pillow by leaning forward on the table before them; and those who still kept awake, had an opportunity, by the faint gleams of a lamp, to study this odd and not over cheerful grouping. One of my companions, not being able to sleep, went on deck and resigned his place to me. I thus got a place for my head, and with my great coat for a pillow, I managed to pass, in a kind of restless sleep, the most dreary portion of the night. Early in the morning, an hour before day-break, I went on deck; a moist fog rested sluggishly on the water, and rendered the shore barely visible. At this time an incident occured which animated every one. A poor Dutch family was on board, consisting of a man, his wife, and four children, and it was suddenly proclaimed that the eldest boy had fallen overboard during the night, and was lost. *A man overboard* is a startling subject on every kind of water, and in every description of craft, and we wereall busy with inquiries as to when and where and by whom he was last seen; search was made in every corner of the vessel, but all to no purpose;—the boy was certainly drowned, and there was no help for it. The father seemed to receive the condolence of the passengers with characteristic Dutch phlegm: he lit his pipe and received in silent resignation a long and apparently angry discourse from his wife; we were all very sorry for him and for her, when, lo! the black tarpaulin, which covered a large collection of goods on deck, was seen to move, and from under one of its folds a large round sleepy face appeared, and crawling forth, with a yawn and a stretch, the object of our solicitude stood before us: the parents expressed their joy in rather an odd manner,—the mother scolded, the father quietly put down his pipe and began to cuff the boy rudely, and, but for the interference of some of the passengers, he would probably have received a sound thrashing for venturing, as it appeared, without leave, to sleep in certainly what seemed to be the most comfortable part of the vessel.

perhaps the dying, come steaming up the same aperture down which the fresh air is struggling to find its scanty way to the miserable inmates, how can we wonder at the mortality of seamen, especially in tropical climates. In troop or transport ships, the constitutions of the men are frequently enfeebled, instead of being strengthened by the voyage. Moreover, the evils arising from want of ventilation are aggravated by the horrors of sea-sickness; the sense of smell becomes morbidly sensitive; the bilge water, or that stagnant corrupt water which lodges in the bottoms of tight vessels, emits the offensive odour of sulphuretted hydrogen and other gases; and these, combined with the closeness of the cabins in sailing vessels, few can endure with impunity; all this is even made worse in steam-boats by the odour of the hot rancid tallow used for greasing the engines.

Mr. Robert Ritchie, in an excellent paper on the ventilation of ships,* quotes a letter from a naval friend on the African coast, who says:—"On the lower deck of our little craft were stowed away one hundred persons, ship stores, cook's coppers, &c. Never did I before feel so much the importance of a thorough ventilation. To sleep in such an atmosphere is next to impossible, and when exhausted nature sinks into repose, it awakes with that sickly and feverish sensation which betokens the derangement of your physical system, and that you have been inhaling a poison which is slowly but surely preying on the vitals of your constitution. That disease and death should be frequent is only what every rational and scientific person would expect. Climate is blamed for every disease that appears in foreign stations, but I have not the slightest doubt that the want of a thorough method of ventilation on ship-board has, in very many cases, laid the system open to disease, which, in more favourable circumstances, could have been easily removed. The man who could improve the present wretched system would be justly entitled to the thanks of every humane and benevolent individual."

* Jameson's *Edinburgh Philosophical Journal.*

Such is the condition of a small crowded sloop of war. In large men-of-war the evils are less, on account of the ventilation of the lower decks by the gun-ports; these, of course, do not exist in merchant vessels; and in the lower, or orlop deck of all ships, there is great difficulty in establishing a constant uniform current of fresh air.

In these introductory remarks, we do not insist upon the necessity of warming our rooms and other enclosed spaces, for that is an art which is practically well understood, and will receive a share of attention in this little work. But if warming is easy and well understood, ventilation is also easy and badly understood; that is, it is very easy to ventilate a room or a building, but the necessity for doing so is not generally admitted by the great mass of the people, nor even by those whose duty it is to teach them and to provide for the practice. But to combine the two arts, to warm a room sufficiently, and at the same time to ventilate it thoroughly, is not easy, for the very means employed to ventilate a room, must necessarily dissipate and carry away the heat employed in warming it. Something, however, may and ought to be done to combine the two methods, as we shall endeavour to shew; but before entering upon practical details, it is necessary to invite attention to such of the laws of heat as are more immediately connected with our subject. We can scarcely do more, in our limited space, than bring together a few of the results of scientific principles, and refer the reader to larger and more comprehensive treatises for their verification.

Heat is given off from bodies by two distinct processes—*radiation* and *conduction*. In radiation, rays of heat diverge in straight lines from every part of a heated surface, and also from extremely minute depths below such surface. These rays, like rays of light, are subject to the laws of refraction and reflection, and their intensity decreases as the square of the distance. When we approach an open fire, or the surface of a stove, we feel its heat by radiation, and it has been ascertained that, at the ordinary temperature of hot water pipes,

about one-fourth of the total cooling effect is due to radiation.

But the amount of radiation of a body heated above the temperature of the surrounding atmosphere depends greatly upon the nature of its surface. If a vessel of hot water, coated with lamp black, radiate 100 parts of heat within a given time, a similar vessel, containing water of the same temperature, coated with writing paper, will radiate 98 parts of heat; resin, 96; China ink, 88; red lead, or isinglass, 80; plumbago, 75; tarnished lead, 45; tin, scratched with sand paper, 22; mercury, 20; clean lead, 19; polished iron, 15; tin plate, 12.

In order to ascertain the velocity of cooling for a surface of cast iron, Mr. Hood selected a pipe 30 inches long, 2½ inches diameter internally, and 3 inches diameter externally. The rates of cooling were tried with different states of the surface; first, when covered with the usual brown surface of protoxide of iron; next it was varnished black, and finally the varnish was scraped off, and the pipe painted white with two coats of lead paint. The ratios of cooling 1° were found to be for the black varnished surface 1.21 minutes; for the iron surface, 1.25 minutes, and for the white painted surface, 1.28 minutes. "These ratios are in the proportion of 100, 103.3, and 105.7; but, as the relative heating effect is the inverse of the time of cooling, we shall find that 100 feet of varnished pipe, 103¼ feet of plain iron pipe, or 105¾ feet of iron pipe, painted white, will each produce an equal effect."*

Leslie found that tarnished surfaces, or such as are roughened by emery, by the file, or by drawing streaks or lines with a graving tool, had their radiating power considerably increased. But, according to Melloni, the roughness of the surface merely acts by altering the superficial density which varies according as the body is of a greater or less density, previous to the alteration of its surface by roughening. The following experiment gives the data for this conclusion: Melloni took four

* *Practical Treatise on Warming Buildings, &c.*, London, 1844.

plates of silver, two of which, when cast, were left in their natural state, without hammering, and the other two were planished to a high degree under the hammer. All four plates were then finely polished with pumice-stone and charcoal, and after this, one of each of the pairs of plates was roughened, by rubbing with coarse emery paper in one direction. The quantity of heat radiated from these plates was as follows:—

Hammered and polished plate........	10°
Hammered and roughened plate......	18°
Cast and polished plate	13.7°
Cast and roughened plate	11.3°

Thus it appears that the hard hammered plate was increased in radiating power four fifths, by roughening its surface, while the soft cast plate lost nearly one fifth of its power by the same process.

When a body is exposed to a source of heat, a portion of it is absorbed, and it has been proved experimentally, that the absorptive power of bodies for heat is precisely equal to their radiative power. It was long supposed that colour had great influence on radiation and absorption. By exposing variously coloured surfaces to the heat of the sun, their absorbing power was in the following order—black, blue, green, red, yellow, and white. Hence it would naturally be expected, that the radiating powers of differently coloured bodies would be in this order, and that by painting a body of a dark colour we should increase its radiating power. Such, however, is not the case, for the absorption and radiation of *simple heat*, or *heat without light*, depend on the nature of the surface rather than on colour. Heat of low temperature, or that which proceeds from bodies of low temperature, becomes less connected with colour the lower the temperature.

The numbers which represent the radiating powers of different bodies for invisible or non-luminous heat, or heat of low temperature (as given above), evidently bear no relation to colour, for lamp-black and writing paper are nearly equal;

Indian ink is much less, and plumbago still less. A thermometer bulb, coated with a paste of chalk, is affected by invisible heat even more than a similar one coated with Indian ink ; but this result does not occur when the heat is from a luminous source. Thus it was found by Scheele that when two spirit thermometers, one containing coloured, and the other colourless alcohol, were exposed to the sun, the coloured liquid rose much more rapidly than the colourless, but when they were both plunged into a vessel containing hot water, they rose equally in equal times.

The propagation of heat by conduction is a very different process from that of radiation. By conduction, the heat travels through or among the particles of solid matter ; and is gradually communicated by one group of particles to the neighbouring group, and by this to the next group, and so on, until the temperature of the body in contact with the source of heat is raised more or less above the temperature of the air. When heat is communicated to a fluid body, the process is different. In consequence of the great mobility of its particles, those which first come under the action of the source of heat, being raised in temperature, escape from its influence, and ascend through the fluid mass, distributing a portion of their acquired heat among other particles on its way ; other particles immediately take its place, and being heated, ascend in like manner, and distribute their heat. By this process of *convection*, as it is called, the whole of the particles in a confined mass of fluid come under the action of the heating body ; those first heated, escape as far as possible from the source of heat, and becoming cooled, descend again to be heated, and again to ascend and descend. In this way a circulation is maintained in the whole mass of fluid.

It is only by this process of convection that air may be said to be a conducting body, for if a mass of air be confined in such a way as to prevent the free motion of its particles, it ceases almost entirely to conduct heat, and may be usefully employed to retain heat ; as in the case of double windows,

the enclosed mass of air prevents the heat from escaping from the apartment, and shields the glass which is in contact with the warm air of the room from the cooling action of the external air. According to some experiments by Mr. Hood, each square foot of glass will cool 1.279 cubic feet of air 1° per minute, when the temperature of the glass is 1° above that of the external air. This, however, is in a still atmosphere. The cooling effect of external windows when exposed to the action of winds has not been accurately determined. It appears that the cooling effect of wind, at different velocities, on a thin surface of glass, such as the bulb of a thermometer, is very nearly as the square root of the velocity. But there are many objections to applying the results obtained from the thin glass of a thermometer bulb to the comparatively thick glass of windows. Glass is a very bad conductor of heat, and the cooling effect of wind upon it is not so great as is generally supposed.

Solids differ greatly in their heat-conducting powers. If gold conduct 100 parts of heat, platina will conduct 98.10 parts; silver, 97.30; copper, 89.82; iron, 37.43; zinc, 36.30; tin, 30.39; lead, 17.96; marble, 23.60; porcelain, 12.20; fire-brick, 11.40. The slow conducting power of such bodies as porcelain, brick and glass, may be contrasted with the rapid conducting power of some of the metals by holding one end of a piece of each substance in a flame; the metal will soon become too hot for the hand, while the porcelain may be heated to redness in the flame without its being felt to be much warmer at the other end. A practical application of this property is also to be found in the materials of close stoves for heating apartments; for while those in which the outer case consists of copper or iron receive their heat quickly and part with it quickly, those which are lined with brick and covered with porcelain receive their heat slowly, and communicate it slowly to the air of the apartment. Much, however, depends on the thickness of the metal casing, for, by increasing this, it will, of course, retain its heat longer.

When a heated body cools under ordinary circumstances, it is by the united effects of radiation and conduction, and the rate of cooling increases considerably, in proportion as the temperature of the heated body is greater than that of the surrounding medium. We have seen that the cooling effect of radiation depends greatly on the nature of the surface; but it is a remarkable fact, that the cooling effect of the air by conduction, has no reference to the nature of the surface; it is the same on all substances, and in all states of the surface of those substances. The air, in contact with such surfaces, robs them of a portion of heat, and immediately ascends to make way for other portions of air, which repeat the process. By these two processes the body cools down to the temperature of the surrounding air, the conductive power of which varies with its elasticity, or barometric pressure; the greater the pressure the greater also the cooling power. It has also been shewn by Dulong and Petit, that the ratio of heat, lost by contact of the air alone, is constant at all temperatures; that is, whatever is the ratio between 40° and 80° is also the ratio between 80° and 160°, or between 100° and 200°.

It was long supposed that a certain relation existed between the radiating and conducting powers of heated bodies, that the variation between them was exactly proportional to the simple ratio of the excess of heat; that is, supposing any quantity of heat to be given off in a certain time, at a specified difference of temperature, at double that difference twice the quantity of heat would be given off in the same time. This law does, to a certain extent, apply where low temperatures are concerned, but does not hold at high temperatures. Thus, in a set of experiments by Dulong and Petit, the total cooling at 60° and 120° (Centigrade), was found to be about as 3 to 7, at 60° and 180°, as 3 to 13; and at 60° and 240°, as 3 to 21; whereas, according to the old theory, these numbers would have been as 3 to 6, 3 to 9, and 3 to 12. When the excess of temperature of the heated body above the surrounding air is as high as 240° Cent., or 432° Fahr., the real velocity of

cooling is nearly double what it would have been by the old theory, varying, however, with the surface.

Since the heat lost by contact of the air is the same for all bodies, while those which radiate most, or are the worst conductors, give out more heat in the same time than those bodies which radiate least, or are good conductors, it might be supposed that those metals which are the worst conductors would be best adapted for vessels or pipes for warming rooms by radiation. "Such would be the case if the vessels were *infinitely* thin; but as this is not possible, the slow conducting power of the metal (iron) opposes an insuperable obstacle to the rapid cooling of any liquid contained within it, by preventing the exterior surface from reaching so high a temperature as would that of a more perfectly conducting metal under similar circumstances; thus preventing the loss of heat both by contact of the air and by radiation, the effect of both being proportional to the excess of heat of the *exterior* surface of the heated body. If a leaden vessel were *infinitely* thin, the liquid contained in it would cool sooner than in a similar vessel of copper, brass, or iron; but the greater the thickness of the metal, the more apparent becomes the deviation from this rule; and as the vessels for containing water must always have some considerable thickness, those metals which are the worst conductors will oppose the greatest resistance to the cooling of the contained liquid."—*Hood.*

The reflective power of different substances for heat is inversely as their radiating power. If a surface of brass reflect 100 parts of heat; a similar surface of silver will reflect 90 parts; tin foil, 85; block tin, 80; steel, 70; lead, 60; tin foil, softened by mercury, 10; glass, 10; glass, coated with wax, 5.

When similar substances are exposed to the same temperature, they all become heated to the same degree, as measured by the thermometer, but if the temperatures of dissimilar substances have to be raised to the same degree, the quantities of heat required for the purpose will be very different for different substances. Thus, if we place side by side, upon a

hot plate, two equal and similar vessels, one containing a certain weight of water, and the other an equal weight of mercury, the mercury will soon become much hotter than the water. So also, on lowering the temperature of dissimilar substances to an equal degree, some will give out more and others less heat. Different bodies, therefore, display different degrees of susceptibility for receiving free heat within their molecules; this is called their *capacity for heat*, and the quantity required to raise equal masses or equal weights 1°, is termed their *specific heat*. The theory of specific heat is of great importance in a practical point of view, for on it depend many of the calculations for ascertaining the proportions of the various kinds of apparatus employed in warming buildings.

The specific heat of different substances can be ascertained by mixing together, with certain precautions, ascertained quantities of the substances under consideration, when their mutual capacities for heat are determined by the decrease in the temperature of the hotter body, and by its increase in the cooler. Thus, if 1lb. of mercury at 32°, and 1lb. of water at 62° be mixed together, the common temperature will be 61°. The temperature of the metal has, therefore, risen 30°, while that of the water has fallen 1°. If the mercury had been at 62°, and the water at 32°, the common temperature of the mixture would have been 33°. In this case the water would have gained 1° of temperature, and the mercury would have lost 30°. Thus it appears that the capacity of water for heat exceeds that of mercury 30 times. If the water be taken as unity, the specific heat of the mercury will be $\frac{1}{30}$, or 0.033.

Again, if 1lb. of iron filings at 68° be mixed with 1lb. of water at 32°, the temperature of the mixture will be 36°. That quantity of heat, therefore, the loss of which lowers the temperature of iron 32°, raises the temperature of water only 4°; so that eight times as much heat is required to raise or

depress the temperature of the water 1°, as would raise or depress the temperature of an equal weight of iron 1°. Hence the specific heat of iron is $\frac{1}{8}$, or 0.125.

The capacity of substances for heat may also be found by observing the quantity of ice which the body under investigation is capable of thawing. Thus, if equal weights of iron and lead be operated on, it will be found that the iron requires a greater quantity of heat than the lead to produce the same change of temperature, in the proportion of nearly 11 to 3. If a bar of iron, in falling from 100° to 95°, melt 11 grains of ice, then a bar of lead of equal weight, under similar circumstances, would melt rather less than 3 grains; heat is, therefore, more effective in warming lead than iron. Again, an ounce of mercury and an ounce of water, in falling from 60° to 55°, will melt quantities of ice, in the proportion of 33 to 1000, or very nearly 1 to 30; that is, to raise water from 55° to 60°, requires a greater quantity of heat than to raise an equal weight of mercury through the same range of temperature, in the proportion of 30 to 1.*

* The quantity of ice melted by different kinds of fuel, affords a convenient method of estimating their relative values. Thus it has been found that

1lb. of	coal, of good quality,	melts	90lbs.	of ice,
„	coke,	„	84lbs.	„
„	wood,	„	32lbs.	„
„	wood charcoal,	„	95lbs.	„
„	peat,	„	19lbs.	„

One method of estimating how much of the heat of a common fire is radiated around it, and how much combines with the smoke, is to allow all the radiant heat to melt a quantity of ice contained in a vessel surrounding the fire, and all the heat of the smoke to melt the ice in another vessel surrounding the chimney. By comparing the two quantities of water thus obtained with the quantities of ice melted, it will be found, according to Dr. Arnott, that the radiant portion of the heat is, in ordinary cases, rather less than the combined, or less than half the whole heat produced.

The specific heat of bodies has been determined not only for equal weights, but also for equal volumes, and this is called their *relative heat*, which is to the specific heat of any substance directly as its specific gravity. It may be found by multiplying the specific heat into the specific gravity; and conversely, the specific heat may be found by dividing the relative heat by the specific gravity. Now as the quantity of heat required to raise the temperature of 1lb. of water 1° is sufficient to raise 1lb. of mercury 30°, we say that the specific heat of mercury is $\frac{1}{30}$, taking water as unity; and since the specific gravity of mercury is about 13.6, it follows that the relative heat of an equal volume of this metal is $\frac{1}{30} \times 13.6 = 0.453$.

With respect to gaseous bodies, it has been found that their specific heat is inversely as their specific gravity or density; and, consequently, equal weights of such gases contain a larger quantity of heat, less their specific gravity. But as the relative weights of equal volumes of gas are inversely as their specific gravities, it follows that equal volumes of these gases will have equal relative heat; that is, they will contain equal quantities of heat as the atmospheric air itself. This, however, refers to mixtures of gases, for when they are chemically combined, they have a different relative heat, which exceeds that of common air, and each such gas has a distinct index to express its relative heat, so that the quantity of heat contained in them exceeds that contained in an equal volume of atmospheric air. The capacity of atmospheric air is taken as the unit by which to estimate the specific heat of gaseous bodies; but sometimes that of water is assumed as the unit, and then the capacities of gases are comparable with those of solids and liquids. The latter values are obtained by multiplying the former into 0.2669, which is the index of the specific heat of atmospheric air compared with that of water.

The following table shews the specific heat of various substances referred to water as the standard, and are supposed to

represent the quantity of heat contained in equal weights of the several substances :—

Water	1.0000	Carbonic acid .	0.2210
Aqueous vapour .	0.8470	Carbonic oxide .	0.2884
Alcohol . . .	0.7000	Charcoal . . .	0.2631
Ether	0.6600	Sulphur . . .	0.1850
Oil	0.5200	Wrought iron .	0.1100
Air	0.2669	Mercury . . .	0.0330
Hydrogen . . .	3.2936	Platinum . . .	0.0314
Nitrogen . . .	0.2754	Gold	0.0298
Oxygen . . .	0.2361		

It appears, however, that bodies do not possess the same capacity for heat at all temperatures, but that it increases with the temperature; the quantity of heat given out by any substance in cooling a given number of degrees, is greater at high temperatures than at low ones.

The method of ascertaining the specific heat of gases is as follows :—The gas to be examined is well dried, and then brought from a vessel, surrounded with water at 212°, gradually through a spiral tube, surrounded by cold water, the gas escaping through the opposite end of the spiral. In the course of its passage, the gas parts with a portion of its heat to the cold water which surrounds the spiral, and the temperature of the water gradually rises, until after some time it becomes stationary. The equilibrium thus established between the water and the gas is measured by a thermometer, so as to find both the rise in the temperature of the water, and the fall in that of the gas. If the experiment be made with some other gas, and the result should give a higher temperature to the water, then this second gas must have imparted to the fluid a greater amount of heat than the former one did; if, on the contrary, the temperature of water be less this time than before, it will have given out less heat, and the respective capacities for heat of these two gases will be proportional to the temperatures of the water through which they have been admitted. The

capacity of atmospheric air being taken as the unit, the specific heat of other gases may be expressed by proportionate numbers. To raise 1lb. of water from 32° to 212°, requires the same quantity of heat as will raise 4lbs. of atmospheric air the same number of degrees. The specific heat of air is therefore $\frac{1}{4}$ or, more exactly, 0.2669 that of water, as stated in the above table.

When heat is added to a solid body, the first effect which marks the increase of temperature is *expansion;* that is, the cohesive or attractive force becomes more and more opposed by the repulsive force of heat; the particles are consequently separated to greater distances, and the temperature rises. At a certain point, however, the temperature, as marked by the thermometer, becomes stationary, and although the heat be continually applied, the temperature does not rise. The solid is now undergoing a change of state; it is passing from the solid into the liquid state; and no rise in temperature will be observed until the whole of the solid has become liquid. The point at which a body begins to fuse or melt, is called its *fusing point* or *point of liquefaction,* and is different in different substances. The quantity of heat absorbed by the body, and unaccounted for, as far as the thermometer is concerned, is called *latent heat.* When the body is liquefied, the temperature again begins to rise, until another point is attained, when it again becomes stationary, and the liquid begins to pass off in the form of vapour or steam. This point is called the *boiling point,* and is different in different substances. The heat absorbed during the process of boiling or vaporization is also called latent.

If, for example, a quantity of snow, at the temperature of zero, with a thermometer in it, be placed in a vessel on the fire, the temperature will be observed to rise to 32°; the snow will then immediately begin to be converted into water, and the thermometer will become stationary at 32°, until the whole of the snow is melted. This temperature is, therefore, the melting or fusing point of snow or ice, and the heat ab-

sorbed or rendered latent during the process, being that which is necessary to produce liquefaction, is hence called also the *heat of liquefaction*, and amounts to no less than 140°; that is, although snow or ice may be of the same temperature as water, yet the water actually contains 140° of heat more than the solid snow or ice. As soon as the whole of the snow is melted, the temperature of the water will begin to rise, and will continue to do so until it reaches 212°, when the boiling point of water is attained. While steam is rapidly escaping, the water remains at 212°; the heat which is absorbed, called the heat of vaporization, being that which is required to maintain water in the state of vapour or steam, amounts to no less than 1000° of temperature; that is, although water may be at 212°, and steam may be at 212°, yet the steam contains a larger amount of heat than water, such as is represented by 1000° on the scale of the thermometer.

In the following table the melting points of a few substances are noted, together with the quantity of heat rendered latent by each in passing from the solid into the liquid state. From these, and other results, it may be seen that, in general, the higher the point of fusion, the greater will be the quantity of heat absorbed in liquefaction. There is, however, no proportion between these effects, for ice and spermaceti melt at 32° and 112°, and yet the quantities of heat rendered latent are nearly the same.

	Melting Point.	Latent Heat.
Water	32°	140°
Sulphur	213°	143.7
Spermaceti	112°	145
Lead	612°	162
Bees' Wax	150°	175
Zinc	773°	493
Tin	442°	500
Bismuth	476°	550

In the following table the boiling points of a few substances

are given, together with the quantity of heat rendered latent by each in passing from the liquid into the aeriform state.

	Boiling Point.	Latent Heat.
Water	212°	1000°
Alcohol (sp. gr. 0.7947)	173° (barom. 29.5)	457
Ether	98°	312.9
Oil of Turpentine	314°	183.8
Nitric Acid (sp. gr. 1.50)	210°	550
Ammonia		865.9
Vinegar		903
Petroleum		183.8

When water is boiling in an open vessel, the steam which escapes from it is of the same pressure and elasticity as the atmospheric air, and at 212° is equivalent to 30 inches of mercury. In a close vessel, however, the temperature of the steam may be increased to any extent, and is only limited by the strength of the vessel containing it. Thus, at 212°, the pressure of the steam is equal to one atmosphere, or 15lbs. on every square inch of surface; at 250°, the pressure of the steam, tending to burst the vessel containing it, is equal to two atmospheres, or 30lbs. on the square inch; at 275°, the bursting pressure is that of three atmospheres, or 45lbs. on the square inch, and so on. But it is a remarkable fact, that at all temperatures and pressures, the steam contains exactly the same absolute quantity of heat; for while the temperature, as measured by the thermometer, increases almost indefinitely, the latent heat of high-pressure steam diminishes in exactly the same ratio, so that the sum of the latent and sensible heat of steam always amounts to 1800° above the freezing point of water. Thus a certain weight of steam at 212°, when condensed into water at 32°, gives out 180° of sensible heat, and 1000° of latent heat=1180°; and the same weight of steam at 400°, condensed into water at 32°, gives out 368° of sensible heat, and 812° of latent heat=1180°. The same fact may be observed with steam at all other temperatures.

These details respecting latent heat will enable the reader to compare the merits of the two systems of heating buildings by pipes filled with hot water, and by similar pipes filled with steam.

In the former system, it is not desirable to raise the water to the boiling point (212°), because, in such case, steam would be formed, and this escaping by the safety pipe, would abstract much useful heat from the apparatus. In the latter system, it is desirable to maintain the pipes at 212°, because, at a lower temperature, the steam would condense, and also absorb much useful heat from the apparatus. From the necessity of maintaining the temperature of 212° in steam pipes, it is evident that a given length of steam pipe will afford more heat than the same quantity of hot water pipe; but the following remarks by Mr. Hood, on the relative permanence of temperature of the two methods, will shew an advantage in favour of the hot water system:—

"The weight of steam, at the temperature of 212°, compared with the weight of water at 212°, is about as 1 to 1694; so that a pipe which is filled with water at 212° contains 1694 times as much matter as one of equal size filled with steam. If the source of heat be withdrawn from the steam pipes, the temperature will soon fall below 212°, and the steam immediately in contact with the pipes will condense; but in condensing, the steam parts with its latent heat; and this heat, in passing from the latent to the sensible state, will again raise the temperature of the pipes. But as soon as they are a second time cooled down below 212°, a further portion of steam will condense, and a further quantity of latent heat will pass into the state of heat of temperature; and so on, until the whole quantity of latent heat has been abstracted, and the whole of the steam condensed, in which state it will possess just as much heating power as a similar bulk of water at the like temperature; that is, the same as a quantity of water occupying $\frac{1}{1694}$ part of the space which the steam originally did.

"The specific heat of uncondensed steam, compared with water, is for equal weights as .8470 to 1; but the latent heat of steam being estimated at 1000°, we shall find that the relative heat obtainable from equal weights of condensed steam and of water, reducing both from the temperature of 212° to 60°, to be as 7.425 to 1; but for equal bulks, it will be as 1 to 228, that is, bulk for bulk, water will give out 228 times as much heat as steam, on reducing both from the temperature of 212° to 60°. A given bulk of steam will, therefore, lose as much of its heat in one minute, as the same bulk of water will lose in three hours and three quarters."

But when the water and the steam are both contained in iron pipes of the same dimensions, the rate of cooling will differ from this ratio, in consequence of the greater quantity of heat contained in the metal than in the steam. The specific heat of iron being nearly the same as that of water, the pipe filled with water will contain 4.68 times as much heat as that which is filled with steam; and if the latter cools down to 60° in one hour, the other will require about four hours and a half to do the same. There are other circumstances to be noticed hereafter, which cause the hot water apparatus to be six or eight times (instead of $4\frac{1}{2}$) more efficient as a source of warmth than steam.

The process of boiling is by no means indispensable to the formation and escape of steam or vapour; for at all temperatures below the boiling point, vapour is formed at the surface of liquids, and escapes therefrom by a process called *spontaneous evaporation.* The difference between this process and ebullition is chiefly this:—when a liquid boils, the vapour which escapes therefrom constantly maintains the same temperature, provided the pressure remain the same; but evapotion may go on at all temperatures and pressures, the quantity of liquid evaporated depending on the temperature and the amount of surface exposed; or the pressure may be increased or diminished, or removed altogether, without affecting the result, or that quantity of vapour which can exist in a given space at a given temperature; the saturation of that space

requiring a longer time in proportion to the density of the air contained in it, while in a vacuum the saturation is instantaneous; this is the only difference.

We have seen that the pressure or elasticity of vapour at 212° is sufficient to support a column of mercury 30 inches high; the force of vapour at lower temperatures is also measured by the length of the mercurial column which it will support. Vapour at 200° will support 23.64 inches of mercury; at 150°, 7.42 inches; at 100°, 1.86 inches; at 80°, 1 inch; at 60°, .524 inch; at 50, .375 inch; at 32°, .2 inch.

The amount of evaporation, however, is greatly influenced by the motion of the air which carries off the vapour from the surface of a liquid as fast as it is formed. A strong wind will cause twice as much vapour to be discharged as a still atmosphere. Dalton ascertained the number of grains weight of water evaporated per minute from a vessel, 6 inches in diameter, for all temperatures between 20° and 212°, when the air was still, or in gentle or brisk motion. When the water was at 212°, the quantity evaporated was 120 grains per minute in a still atmosphere; 154 grains per minute with a gentle motion of the air, and 189 grains per minute with a brisk motion of the air. The following is an extract from his table between the temperatures of 40° and 60°:—

Temp. Fahr.	Force of vapour in inches of mercury.	Evaporating force in grains of water. Still.	Gentle.	Brisk.
40°	0.263	1.05	1.35	1.65
42°	.283	1.13	1.45	1.78
44°	.305	1.22	1.57	1.92
46°	.327	1.31	1.68	2.06
48°	.351	1.40	1.80	2.20
50°	.375	1.50	1.92	2.36
52°	.401	1.60	2.06	2.51
54°	.429	1.71	2.20	2.69
56°	.458	1.83	2.35	2.88
58°	.490	1.96	2.52	3.08
60°	.524	2.10	2.70	3.30

The amount of spontaneous evaporation is also greatly influenced by the quantity of vapour already existing in the air. In order to find this, we must ascertain the *dew point* of the air, or the temperature at which the vapour in the air begins to condense, and then, by referring to the table, the quantity of vapour in the air at the time can be found, and this, deducted from the quantity shewn by the table to be given off at the ascertained temperature of the evaporating liquid, will give the quantity of water that will be evaporated per minute. In finding the dew point, we must bring some colder body into the air, or have the means of cooling some body to such a point as shall just condense the vapour of the air upon its surface. Dr. Dalton used a very thin glass vessel, into which he poured cold water from a well, or cooled down the water by adding a small portion of a freezing mixture. If the vapour was instantly condensed, he poured out the cold water and used some a little warmer, and so on, until he could just perceive a slight dew upon the surface. The temperature at which this took place was the dew point. In Daniell's hygrometer, the cold is produced by the evaporation of ether. Now suppose the dew point of the air to be 40°, and the temperature of the air and of the evaporating liquid to be 60°, with a still atmosphere, the vapour in the air, as shewn by the table at 40°, is 1.05 grains, which subtracted from that at 60°, or 2.10, gives 1.5 grains per minute as the quantity of vapour given off from a surface six inches in diameter.

During the spontaneous evaporation of wet surfaces, a considerable degree of cold is produced by the quantity of heat rendered latent by the formation of the vapour, and the heat is mostly derived from the liquid itself, or the surface containing it. By proper contrivances, water may be frozen, in consequence of the abstraction of heat during the rapid formation of vapour. When a person takes cold from wearing wet clothes, the vapour from the wet clothes obtains its heat from his body, and the chilling sensation is often the greater

the warmer the air. A person with damp clothes, entering a room filled with hot dry air, is very likely to take cold, on account of the powerful effect of warm air in abstracting moisture.

In a badly ventilated room, the moisture from the breath of the inmates, and from the combustion of lamps and candles, accumulates nearly to the point of saturation. This is well shewn by an experiment of the late Professor Daniell. The temperature of a room being 45°, the dew point was 39°; a fire was then lighted in it, the door and window shut, and no air was allowed to enter; the thermometer rose to 55°, but the point of condensation remained the same. A party of eight persons afterwards occupied the room for several hours, and the fire was kept up; the temperature rose to 58°, and the point of condensation rose to 52°. Now, if this room had been properly ventilated, the vapour would have been removed as it was formed, and with it the effluvia and impure air.

PART I.

CHAPTER I.

ON THE METHODS OF WARMING HOUSES BY MEANS OF OPEN FIRE PLACES, ETC., BEFORE AND AFTER THE INTRODUCTION OF CHIMNEYS.

Some useful and instructive results are obtained from the inquiry, how far the physical structure and mental character of classes of persons are influenced by the comparative scarcity and abundance of some of the prime necessaries of life. According to some writers, the unequal distribution of solar heat over the earth, is the cause of marked differences in national character; others refer the distinctive effects to the quality of the air they breathe. According to Arbuthnot, air not only fashions the body and the mind, but has also had great influence in forming language. He imagines that the close serrated method of speaking among northern nations, was owing to their reluctance to open their mouths widely in cold air, whence their speech abounds in consonants. So, on the contrary, the natives of hot climates opening their mouths wider, formed a softer language, and one abounding in vowels. The Greeks, inhaling air of a fine temperate region, spoke with open mouth, and toned their voice to sweet sonorous accents.

But if such views as these be regarded as fanciful, there is, however, much truth in the proposition, that the ease or difficulty with which fuel is procurable, has a great effect in promoting or interfering with the health and personal com-

forts of nations; and that these, by a reflex action, contribute much to the formation of character. It has been remarked, that formerly the county of Buckingham being overgrown with wood, it was thought necessary to clear it away, on account of the refuge it afforded to the numerous robbers who infested the district. The people being thus deprived of fuel, became in the course of time stunted in growth and dulled in intelligence; until, by the extension of inland navigation, fuel became cheap, and then the inhabitants began to improve. In the county of Lancaster, on the contrary, the great abundance and cheapness of fuel are extremely favourable to health and comfort, and hence, according to Sir Gilbert Blane, the Lancasterians, especially the females, have become noted for their well-formed persons and handsome faces. In Yorkshire, and other parts of England where fuel is abundant, the people are generally well-grown, healthy, and intelligent, and their average height is said to exceed that of the inhabitants of other parts of England where fuel is scarce. The Norwegians are generally well lodged, each house being furnished with glass windows, and an iron kakle or stove, and on this account they are a better grown race than the North-Western Highlanders of Scotland, who procure their fuel with difficulty, and consume it in a rude and unthrifty manner. In France, where fuel is very scarce, the average height of a man does not exceed 5 feet 4 inches; in the Netherlands where fuel is more abundant, the average height is 5 feet $6\frac{1}{3}$ inches; and in England, where fuel is cheap and abundant, the average height is upwards of 5 feet 9 inches; in Sweden, where wood is as abundant as our coal, the peasants are tall, vigorous men, notwithstanding their uncleanly habits and the rigour of the climate.

The comparative scarcity or abundance of fuel will, of course, greatly determine the method of creating an artificial climate within doors. In some parts of China, where fuel is scarce, the people secure themselves from the cold of winter by warm clothing, and this is probably a safer method even

than our own, because with them the defence is constant and uniform, while our in-door clothing is thin, and we rely for warmth upon an atmosphere heated to the temperature of summer. If the person be well clothed, the coldest atmosphere can be breathed with safety, and its effect is often highly exhilarating, as in skating on the ice or in walking briskly. We often enjoy the warmth of a bed while breathing an atmosphere cold enough to freeze the water in the ewer. Hence it is better, as Dr. Arnott remarks, to clothe so as to feel comfortably warm in a room heated to 60°, or 62°, as a steady temperature, which it would not be dangerous to enter or to leave, than to dress lightly in a room heated by a common fire to 70°, or more, and which is liable to sink to 50°, or less.

In Normandy, where the cold of winter is severe, and fuel expensive, the lace-makers, in order to keep themselves warm, and at the same time to save fuel, agree with some farmer, who has cows in winter quarters, to rent the close sheds. The cows are tethered in a row on one side of the shed, and the lace-makers sit cross-legged on the ground on the other side, with their feet buried in straw. The cattle, being out in the fields by day, the poor women work all night for the sake of the steaming warmth arising from the animals.

The Laplander, during eight months of the year, inhabits a little hut with a small hole in the centre of the roof for the admission of light and the escape of smoke, and obtains heat from a smoky lamp of putrid oil, as the Esquimaux does in his hut of snow. The effect of this arrangement is, that the whole nation of Laplanders are afflicted with blear eyes. The Greenlander, indeed, builds a larger hut, and contrives it better, but it is often occupied by half a dozen families, each having a lamp for warmth and for cooking, and the effect of this arrangement, says Egede, "is to create such a smell, that it strikes one not accustomed to it to the very heart." We fear that a similar effect would be produced on any one of our readers, were he to enter the huts of some of the Irish and Scottish peasantry.

The method of obtaining warmth in Persia, is scarcely an improvement on the smoky lamp of the Laplanders and Greenlanders. A large jar, called a *kourcy*, is sunk in the earthern floor, generally in the middle of the room. This is filled with wood, dung, or other combustible; and when it is sufficiently charred, the mouth of the vessel is shut in with a square wooden frame, shaped like a low table, and the whole is then covered with a thick wadded quilt, under which the family, ranged around, place their knees to allow the hot vapour to insinuate itself into the folds of their clothing; or when they desire more warmth, they recline with the quilt drawn up to their chins. The immoveable position necessary for receiving the full benefit of the glowing embers is inconvenient; and the effluvia from the fuel is nauseous and deleterious. Headache is always produced, and, from the number who sleep entirely under the quilt at night, suffocation is not an uncommon accident. The kourcy also serves for an oven, and the pot is boiled on its embers. This rude and unwholesome method is adopted in the noblest mansions of the cities, as well as in the dwellings of the poorer classes; only, in the former, a more agreeable fuel is burnt, and the ladies sit from morning till night under rich draperies spread over the wooden cover, endeavouring to overcome the soporific influence of the foul air by occasional cups of coffee, or the delightful fumes of the kalioum.

The burning of fuel in the midst of an apartment, is by no means confined to nations whom we are in the habit of calling barbarous and uncivilised. In Seville and other parts of Spain, preparations for winter are made about the middle of October. The lower summer apartments are stripped of their furniture, and the chairs and tables are removed to other rooms on the opposite side of the court. The brick floors are covered with thicker mats than those used in the warm season. A flat and open brass pan, about two feet in diameter, raised a few inches from the ground by a round wooden frame, on which those who sit near it may rest their feet, is used to burn a sort of

charcoal, made of brushwood, called *cisco*. The carbonic acid vapour is most injurious to health; but such is the effect of habit, that the natives are seldom aware of the inconveniences arising from the stifling fumes of their braziers.

The charcoal brazier is a very ancient method of warming an apartment; the Greeks and other nations commonly used it, and sought to correct the deleterious nature of the fumes, by burning costly odorous gums, spices, and woods.

The braziers of the Romans were elegant bronze tripods, supported by satyrs and sphinxes, with a round dish above for the fire, and a small vase below to hold perfumes. A kind of close stove was also used; but, in either case, the smoke was so considerable, that the winter rooms were differently furnished from those appropriated to summer use. The former had plain cornices and no carved work or mouldings, so that the soot might be easily cleared away. In order to prevent the wood from smoking, the bark was peeled off, and the wood kept long in water, and then dried and anointed with oil. It is not, however, evident how this plan should prevent the smoke of the burning fuel.

The great convenience of the brazier, and the apparent cleanliness of the fuel, are arguments in favour of its continued use even in our own day. A visitor to some of our beautiful cathedrals in winter, during the time of divine service, Salisbury Cathedral for example, will be astonished to see on the floor of the choir two or three enormous braziers full of live charcoal; a peculiar odour arises from them, and pervades the building; a pleasing sensation creeps over the whole frame, and the tendency to sleep is often irresistible; persons troubled with cough cease to cough, and an unusual effort is required when the service is over to rise and quit the building. The enormous size of the enclosure prevents any fatal effects from the abundant evolution of carbonic acid, nor have we ever heard of any well-authenticated case of injury to any one; but a very little consideration will shew that, in a smaller space, such as a room, this primitive method of obtaining warmth

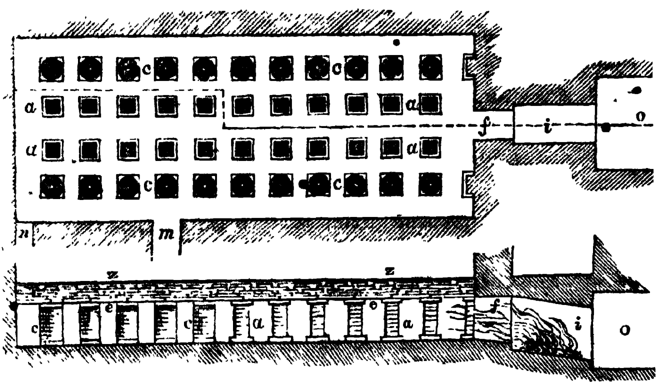
might lead to dangerous consequences. A single pound weight of charcoal consumes in burning $2\frac{6}{10}$lbs. weight of oxygen, which is the quantity contained in between 13 and 14lbs. weight of atmospheric air. Now, a good-sized room, 20 feet by 13 feet, and 10 feet high, does not contain more than about 200 pounds weight of air, and as the combustion of one pound of charcoal produces $3\frac{6}{10}$lbs. of carbonic acid, which, by mingling with the rest of the air of the apartment, renders, at least, 36lbs. weight of air unfit for respiration, making in all about 50lbs. weight of air, it follows that, in such a room, the air will require, for healthy respiration, to be renewed many times an hour.

The fatal effects of the charcoal brazier, in a close room, are too frequently illustrated in the deaths of suicides, as recorded in our newspapers. At the time we are writing, a picture dealer, near Hanover Square, has just availed himself of this fatal instrument. But, perhaps, the most remarkable case of self-destruction in this way, is that of the promising son of Berthollet, the celebrated chemist, for the fatal act was conducted with all the method and precision of a scientific experiment. This young man became affected with great mental depression, which rendered his life insupportable to him. Retiring to a small room, he locked the door, closed up every chink and crevice which might admit fresh air, carried writing materials to a table, on which he placed a seconds' watch, and then seated himself before it. He now marked the precise hour, and lighted a brazier of charcoal before him. He continued to note down the series of sensations he then experienced in succession, detailing the approach and rapid progress of delirium, until, as time went on, the writing became larger and larger, more and more confused, and at length illegible, and the young victim fell dead upon the floor.

In many trades, the workmen are habitually exposed to the fumes of burning charcoal :—bookbinders, engravers, cooks, &c., suffer much in health from this cause ; and it is rare to find that any means are taken to ventilate the places in which they work.

In addition to the brazier, the ancient Romans were acquainted with flues for warming rooms and buildings; but as these were costly contrivances, their use was confined to the wealthy. These flues, forming what was called the *hypocaustum*, were conducted below the floor of the room intended to be warmed. The hypocausts were of two kinds—the first, constructed with flues running under the floor, and heated from a fire-place on the outside of the building; and the second kind formed like a low chamber, having its ceiling supported by small pillars or by dwarf walls, and sometimes with flues leading from them to other apartments. The hypocaust discovered at Lincoln, of which figures 2 and 3 are a ground plan and a section, will explain this construction.

Figs. 2 and 3.



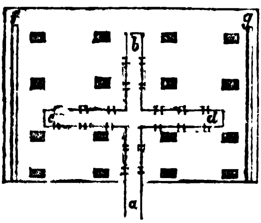
This hypocaust was 24½ feet long and 9½ feet wide; it contained four rows of brick pillars, *a a*, *c c*, two of which were square and two circular. The square pillars, *a a*, were 8 inches on the side and about 9 inches apart; the circular ones, *c c*, were 11 inches in diameter. Each pillar rested on a brick or tile for its base, and another tile formed its capital; thus making its height, which was that of the heating chamber, about 26 inches. The ceiling of the hypocaust was formed of large bricks; on them were placed courses of tiles, bedded in mortar, and on them a layer of stucco, to form the floor of the

room *z* to be heated; the entire thickness of the floor being about 10 inches. The fire-hearth was at *i*; and the flame and smoke passed through the arched cavity or throat of the furnace *f* into the hypocaust. Two flues, *m n*, opened into the hypocaust; the flue *m*, which probably conducted the smoke and hot air under some other apartment, was about 6 inches high and 14 inches inside; its bottom was raised about 2 inches above the floor of the hypocaust. The flue *n* was about 6 inches square, and placed as much under as above the floor of the hypocaust; this seems to have been a smoke flue. The position given to these flues was probably intended to retain at all times the hottest portion of the vapour in contact with the ceiling of the hypocaust. The floor of the præfurnium was 18 inches under the level of the floor of the hypocaust. The large space provided for the combustion of the fuel and the entrance of air, was necessary for conveying a heated current through the flues, as the Romans were unacquainted with the method of procuring a draught by the use of a chimney. Some approach, however, appears to have been made towards the invention of a chimney, for Vitruvius, in describing the construction of the hypocaust for heating the *caldarium* or sweating room of a bath, directs that the floor be made inclining, so that a ball placed on any part of it would roll towards the fire-place, by which means the heat would be more equally diffused in the sweating chamber.

The hypocaustrum is well known to the Chinese, and is in common use about Pekin, where the winter climate is very severe. The houses of the better class are built with double walls and with hollow flues extending beneath the floors. The fire-place is constructed either against the exterior wall of the apartment to be heated, or in an inferior room adjoining; by which means the annoyance from dust and smoke are avoided, as well as the inconvenience of servants entering the room to attend to the fire. From the fire chamber proceeds a main flue, which is connected with the horizontal flue, *a b*, (Fig. 4). From this another flue, *c d*, proceeds at right angles to about three fourths of the extent of the room; these flues are per-

forated with holes at proper distances, in order to give out the smoke and heated air equally over the whole area of the flooring. Two horizontal flues are built in or attached to the side walls, as at *f g*, in order to carry off the smoke into the external air. The flooring of the apartment consists of flat tiles or flagstones,

Fig. 4.



neatly embedded in cement, so as to prevent the escape of the smoke or heated air from the flues beneath into the room; these stones or paving tiles, resting on blocks of stone or bricks, may be of any thickness required for the extent of the air flues which are employed. By this contrivance, the heat, coming in contact with every part of the floor, is uniformly diffused over the apartment. The floors, also, being very imperfect conductors of heat, being once sufficiently heated by the flues, and the apertures of the main flues outside being stopped, retain a sufficient heat for domestic comfort during many hours. The paving tiles of the rooms are often made of ornamental porcelain ware of considerable thickness. Even the benches and sleeping places are warmed by this contrivance. These are built hollow, with bricks, in the form of a square bench or oblong bed, and communicating with the flues, or having their own separate flue, are thus heated. Those who dislike lying on the hot bricks, or on the felt mat that is spread over them, suspend from the ceiling over the heated bench a kind of hammock, made of coarse cloth; and thus they enjoy warmth and repose. In the morning, the bed places are covered with carpets and mats, on which the inmates sit.

The ingenious economy of the Chinese (from which we might often borrow a useful lesson), prevents the flues from becoming choked by soot. Instead of employing pit coal of good quality, they make use of the inferior or small refuse coal for this purpose,* and mix it with a compost of clay, earth, cow-

* It is worthy of reproachful remark, that during many years the

dung, or any refuse vegetable matter; and then form it into balls, which are dried in the sun or open air. This method is not adopted on account of any scarcity of fuel, for coal is abundant in China; but the Chinese, unlike the English, know how to take care of it. They find that their fire-balls, during combustion, give out very little smoke; and they are largely manufactured in the coal districts, and distributed by canal carriage over a large portion of the empire.

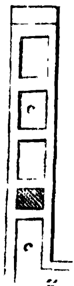
In the inferior class of houses, instead of having the fire outside the house or room to be heated, it is built in the corner of the dwelling room. A pit is dug for the body of the fire chamber and draught-hole; and the top, or head of the stove, is used for the different operations of cooking.

That no portion of heat may be lost, or escape into the room directly from the fire, beyond what is necessary to maintain a given temperature, vessels of water are placed on the head of the stove, and thus the heat, which would otherwise be lost, is absorbed and economised; while it affords, by its evaporation, the necessary supply of moisture to preserve the atmosphere of the room in a healthy condition as to moisture.

The Chinese call a stove which is heated by a furnace, a *kang*; the *ti-kang* is a furnace of which the flue runs under the floor or pavement of a room; and the *kao-kang* is that used for heating benches and beds. There is yet a third variety, the *tong-kang*, which is formed in the wall, and this differs from the *ti-kang* only in being perpendicular instead of horizontal. In the *tong-kang*, the heating flue is carried along the floor, with openings from it, at which the heated air and smoke ascends into the spaces of a hollow wall. A *tong-kang* was erected by Sir William Chambers, in 1761, for heating the orangery at Kew Palace. In imitation of the Chinese method, he introduced heated air through an air pipe or flue in contact with

coal owners of the north of England burnt to waste their small refuse coal at the mouth of the pit. A million tons a year have thus been wantonly destroyed; it is now, however, used for manufacturing coke for the use of our locomotive engines.

Fig. 5.



the heating flues. In Fig 5, the flue from the furnace is shewn at *a*, the *tong-kang* flues at *c*, and the hot-air flue at *e*.

It is scarcely possible to improve upon these refinements of the Chinese, except by the introduction of the chimney, the origin of which has been the subject of much learned discussion. The *tong-kang*, or perpendicular flue, is in effect a chimney, and doubtless acts as such. Before the introduction of this important addition to domestic comfort, about the fourteenth century, the houses, even of the wealthy, must have been wretched abodes, at least according to modern ideas of comfort. "The spacious lofty hall, left open to the roof, had its windows placed high from the floor, and filled with oiled linen or louver boards, or occasionally with painted glass. Its clumsy unframed doors were opened by latches; and when the walls were not coarsely painted in the fashion of the time, they were left rough, and covered with arras, suspended by hooks, at a distance of three or four inches from the wall. The floor, of stone or earth, had a part at one end raised a little above the general level, and laid with planks. On this platform or dais stood a massive table and ponderous benches or forms, and a high-backed seat for the master, under a canopy. On the hearth, in the middle of the hall, were placed the andirons for supporting the ends of the brands, that were arranged by means of a heavy two-pronged fork, the type and predecessor of the modern poker. On the roof, over the hearth, was a turret or louver, filled with boards, so arranged as to exclude rain and wind, and permit the escape of smoke; and this was sometimes an object of considerable architectural beauty in the external aspect of the building." In modern halls, the louver is still retained as an architectural feature, although the uses for its erection have happily long ceased to exist.

"In this gaunt and aguish apartment, heated by a single fire, the company were in a position not much different from what they would be in the open air; not a particle of heated air could add to their comfort, for, as fast as produced, it

escaped through the louver: light was the only solace the greater number could derive from the blazing fuel; and the few who were in a situation to feel the radiant heat, were incommoded by the current of cold air sweeping like a hurricane along the floor towards the fire. From the height of the louver, and low temperature of the smoke, few of the buoyant flakes of charcoal found their way into the atmosphere, and the larger the bonfire, the thicker was the layer of soot deposited on each individual. Boisterous weather also brought its annoyance. Had the fire been made in an open field, they might have moved to the windward of the smoke; but in the hall, where could they flee from its miseries?"*

The houses of small landholders and farmers were generally ne story high, and if of two stories, the roof was so deep, as to shut out the light from the upper rooms. The hall and kitchen formed one apartment, which was open to the timbers of the roof, and, in some cases, was furnished with a louver and a window, that could be closed with a shutter. When these houses had a separate sleeping apartment, old and young occupied it, and several reposed in one bed. Servants slept on the kitchen floor. Cottages had neither louver nor loupe, and the inmates slept round the fire.

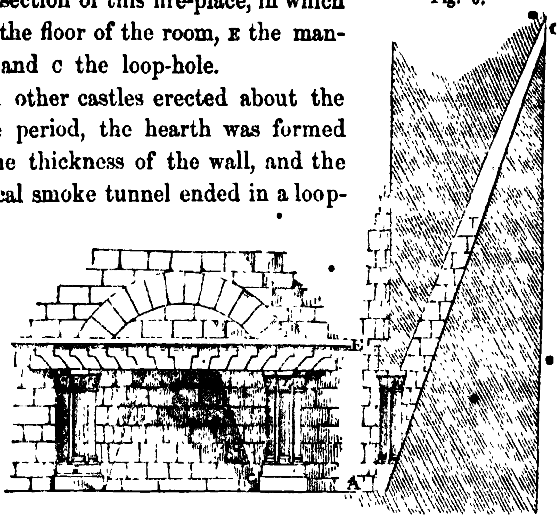
The strongholds which were built about the time of the conquest, were several stories in height, and their roofs being used as a terrace for defence, the central hearth and louver were impracticable. The necessity of providing some exit for the smoke seems to have stimulated invention, and, accordingly, we find the germs of the modern fire-place and chimney in one of these strongholds. In the great guard-room of Conisborough Castle, erected in or near the Anglo-Saxon period, is

* On the *History and Art of Warming and Ventilating Rooms and Buildings*, &c., by Walter Bernan, Civil Engineer. 2 vols. London, 1845. We take this opportunity of acknowledging our obligations to these useful and instructive essays, in which the writer has collected a large store of materials on the subject of warming and ventilation, and the "progress of personal and fire-side comfort." To any one who desires to study the subject in detail, these volumes will prove acceptable.

a large fire-hearth. The mantel is supported by a wide arch, with two transom stones running under it; the back of the fire-place, where it joins the hearth, is in a line with the walls of the room, and the recess at the mantel is formed by the back of the fire-place sloping outwards, as it rises into the thickness of the wall, until it reaches a loop-hole on the outside, where the smoke finds an exit. Fig. 6 is an elevation and section of this fire-place, in which A is the floor of the room, E the mantel, and C the loop-hole.

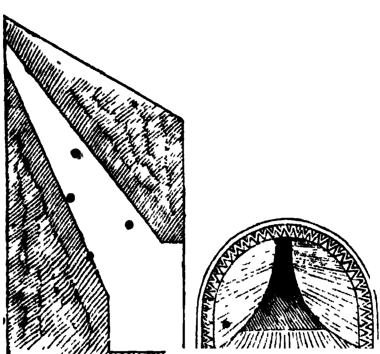
In other castles erected about the same period, the hearth was formed in the thickness of the wall, and the conical smoke tunnel ended in a loop-

Fig. 6.



hole, as at Conisborough Castle. Fig. 7 is another elevation and section of these ancient contrivances for carrying off the smoke. It is from Rochester Castle. In the old palace at Caen, which was inhabited by the conqueror while he was Duke of Normandy, the great guard chamber contains two spacious recessed fire-

Fig. 7.



hearths in the north wall, still in good preservation, from which the smoke was carried away in the same manner as in the above examples.

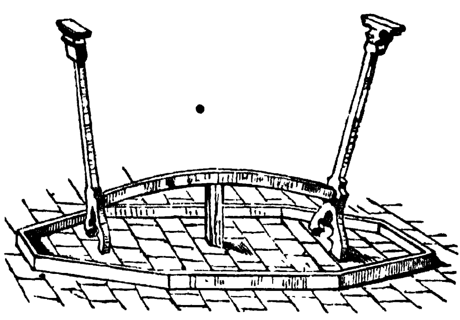
The transition from these contrivances to the common chimney would seem to be easy; but history has failed to record the inventor, or to define the place where the chimney was first used. Chimneys seem to have been common at Venice before the middle of the fourteenth century. An inscription over the gate of the school of Santa Maria della Carita states, that in 1347, a great many chimneys were thrown down by an earthquake, a fact which is confirmed by John Villani, who refers the event to the evening of the 25th of January. Chimneys had also been in use at Padua before 1368, for in that year Galeazo Gataro relates, that Francisco da Carraro, lord of Padua, came to Rome, and finding no chimneys in the inn where he lodged, because at that time fire was kindled in a hole in the middle of the floor, he caused two chimneys, like those that had been long used in Padua, to be constructed by the work-people he had brought with him. Over these chimneys, the first ever seen in Rome, he affixed his arms, which were remaining in the time of Gataro. Winwall House, in Norfolk, which has been described as the most ancient and perfect specimen of Norman domestic architecture in the kingdom, has not only recessed hearths, but flues rising from them, carried up in the external and internal walls. Now, if Winwall House really be an Anglo-Norman edifice, its chimneys must have been built in the twelfth century, and, consequently, the claim of the Italians to the invention cannot be supported. The chimneys at Kenilworth and Conway were also probably erected anterior to the date of those on which the Italians rest their claim. Leland, also, in his account of Bolton Castle, which he says was "finiched or Kynge Richard the 2 dyed," notices the chimneys. "One thynge I muche notyd in the hawle of Bolton, how chimeneys were conveyed by tunnells made on the syds of the walls betwyxt the lights in the hawle, and by

this means, and by no covers, is the smoke of the harthe in the hawle wonder strangely conveyed."

It is not our duty to trace the further history of the chimney, nor to notice the methods by which the chimney shaft became so prominent and beautiful a feature in buildings during the reigns of the Tudors. It is sufficient to remark, that when once introduced in England, the merits of chimneys were soon appreciated, for we find it stated, that in the reign of Queen Elizabeth, apologies were made to visitors if they could not be accommodated with rooms provided with chimneys, and ladies were frequently sent out to other houses, where they could have the enjoyment of this luxury, for such it must be called at this period, when the poorer class of houses was not yet furnished with it.

Wood was the ordinary fuel 'till the seventeenth century, and this was burnt on the capacious hearth, the logs being

Fig. 8.

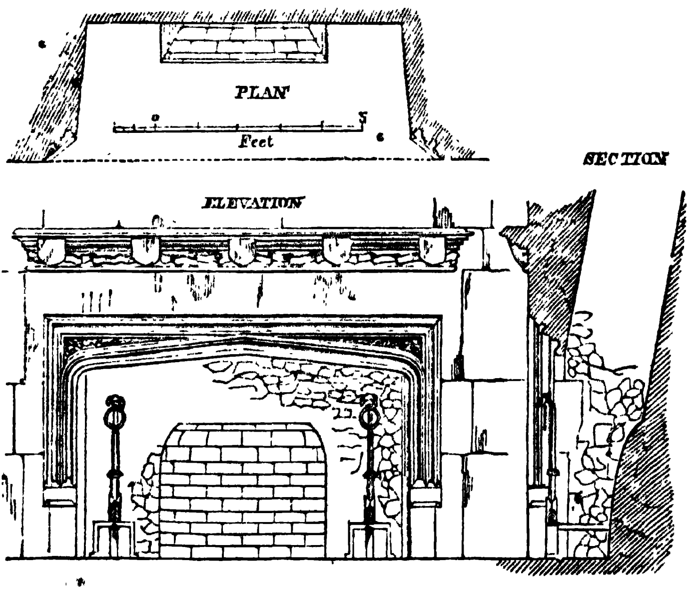


confined within the two standards (Fig. 8) of the andiron, their ends resting on the billet bar, for the purpose of admitting the air below them, and thus promoting combustion. For the large kitchen fire, the standards and billet bars were very strong and massive, but usually quite plain. In the hall, that ancient seat of hospitality, they were also strong and massive, to support the weight of the huge logs; but the standards were kept bright, or ornamented with brass rings, knobs, rosettes, heads and feet of animals, and various grotesque

forms. In kitchens, and in the rooms of common houses, the andiron, as its name implies, was of iron; but in the hall, the standards were of copper or brass, and sometimes of silver. The spacious receptacle was furnished with seats on each side of the hearth, and the snug chimney corner was the post of honour. When the whole family assembled to enjoy a leisure hour, it was round the hearth that they sat; with it was associated their ideas of domestic comfort and conviviality, and the word *hearth* became synonymous with *home*. In some of our rural districts, the custom is still retained of the whole family sitting under the capacious chimney-breast, and it is an honoured custom which we hope may long continue to exist.

In smaller rooms, where the fire was made in a wide and deep recess, each standard was fixed into the back of the hearth by a lateral bar. Thus in Figs. 9, 10, and 11, which

Figs. 9, 10, 11.



represent the andirons in the hall at Vicars Close, Wells, will be seen the standards, the billet bar, and the reredos or

hob, which in deep recesses brings the fire now into the room. When the hearth was of moderate size, the andiron was moveable.*

So long as wood existed in abundance, coal was not sought after for the purposes of domestic fuel; it was supposed that the fumes of coal had a peculiarly corrupting effect upon the air, and were most injurious to health. Its value, however, was appreciated by brewers, dyers, smiths, and others, whose occupations lead to the consumption of a large quantity of fuel, and towards the close of the thirteenth century, coal was imported into London from Newcastle, for the use of those trades. In 1306, however, parliament petitioned the king to prohibit the use of the noxious fuel in the city. A royal proclamation was accordingly issued, prohibiting the use of coal, and as this failed in its effect, a commission was issued for the purpose of ascertaining who burned sea-coal within the city and its neighbourhood, and to punish them by fine for the first offence, and by the demolition of their furnaces if they persisted; but even these severe proceedings failed to put down the nuisance. A law was, therefore, passed, making the burning of sea-coal within the city a capital offence, and permitting its use only in the forges of the neighbourhood. In the reign of the first Edward, a man was tried, convicted, and executed, for burning sea-coal in London. Even in districts where coal abounded, it was not used as a domestic fuel, for we read that in 1349, in the religious house at Whalley, peat, with a very little wood, was the only fuel used.

So deeply rooted was the prejudice against coal, that it was not until the commencement of the seventeenth century that its use became more general. Ladies had an idea that a coal fire injured their complexions, and they would not even enter a house or room where the obnoxious fuel was used; nor would they even partake of meat which had been roasted at a

* On the mantel shelf is a scroll, bearing an inscription, which solicits the prayers of the Vicars in favour of Sir Richard Pomroy, and expresses solicitude for the safety of his soul.

coal fire. When Ben Jonson had to entertain a party of guests at his house, he warmed his room with a charcoal fire; but, on ordinary occasions, he used coal, for we find that, on more than one occasion, his flue caught fire from an accumulation of soot.

In an inventory, dated 1603, of the goods of Sir Thomas Kytson, at Hengrave Hall, in Suffolk, mention is made of "a cradell of iron for the chimnye to burne sea-cole with," and also "j fier sholve made like a grate to seft the sea-cole with." The cradle here mentioned was probably nothing more than a few bars bent into a semicircle, and fastened into the upright wall over the hearth.

There was, doubtless, good reason for the objections of our ancestors to the use of sea-coal, for the chimney fire-places were usually made in the form of a large square recess, and the breast of the chimney was of the same size as the recess itself. In order to rid sea-coal of its noxious sulphurous vapour, Sir John Hacket and Octavius de Strada proposed, in 1626, to convert the coal into coke, and thus make it as agreeable a fuel for chambers as wood and charcoal. A patent was obtained for the purpose, but the speculation did not succeed, as the vapour given off by the coke was found to be nearly as unpleasant as that from coal.

About this time, a great improvement was made in France in fire-places. Louis Savot, in his *Treatise on Architecture*, remarks that large rooms only are free from smoke, and that when fires are made in small apartments, a door or a window had to be left open, or else the air came down the wide flue, and drove the smoke into the room. To correct this defect, he raised the hearth about four inches, and lowered the mantel so as to make the opening of the fire-place about three feet high. The width between the jambs was reduced to three feet; the jambs from the mantel were to be carried up sloping to the waist, or where the flue begins to be of uniform width, and the opening of the fire-place was formed like an arch. But, where the fire-place could not be conveniently altered, Savot perfo-

rated with small holes a plate of iron, whose width and length was nearly equal to the hearth, and this was fixed three inches above the tiles of the common hearth. On this perforated plate he placed a *grill de fer* of the same length as the billets to be burned, and raised nine inches above the plate; the wood was placed on the grate, the charcoal on the perforated plate, and the hearth received the ashes; the air, rising through the small holes, made the charcoal burn briskly, and this so much assisted the burning of the wood, that a rapid draught up the chimney was established, and smoke prevented.

In Savot's description of the fire-place used to heat the "Cabinet des Livres," at the Louvre, we have the first recorded attempt at combining the cheerfulness of an open fire with the economy of an enclosed stove. Fig 12 is a front

Fig. 12.

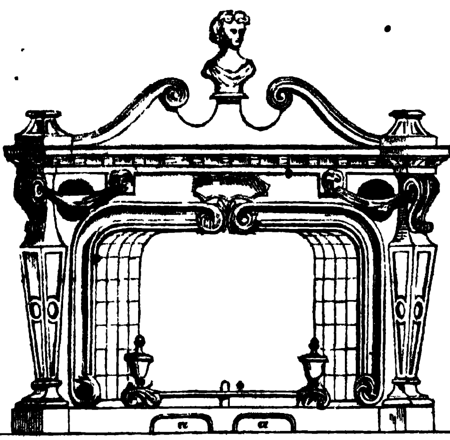
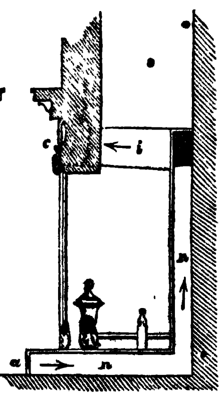


Fig. 13.

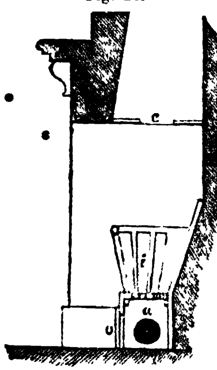


r, and Fig. 13 a vertical section of this ingenious contrivance. The hearth was a thick iron plate placed above the old hearth, with an interval, *n*, of three inches between them. The two sides, or covings of the fire-place, were also formed of thick iron plates, placed three inches from the jambs. The space, *n*, at the back, and the spaces at the sides, communicated with the space, *n*, under the hearth; two pipes, or channels, *i*, communicating with these hollow spaces, opened

into the room at *c*, as shown by the dotted line in the section; these spaces could be closed at pleasure. When the fire was burning, the iron hearth, and the plates which formed the sides or covings, and the back, became very hot. The cold air at the floor, entering by the openings at *a*, into the space *n*, was heated by the hearth, and rising into the spaces at the back and sides, had its temperature further increased; it then entered the channels *i*, and escaped at *c*, thus diffusing an agreeable warmth over the whole room.

About the year 1658, the project for burning coke, instead of coal, was revived by Sir John Winter, who invented an improved fire-place for the purpose. The cradle, or fire-cage, was placed on a box about eleven inches high, in the front of which was an opening, *o* (Fig. 14), fitted with a door, which was always kept closed, except when the ashes were removed. A pipe, *a*, inserted into the side of the box, communicated with the external air, at a level of two or three feet below the bottom bars of the fire-cage; this pipe could be closed at pleasure by a valve. When the coke, or charked coal in the fire-cage, did not burn well, the valve was opened, and the air from the outside rushed in a strong current into the box, and, by its powerful blast, soon roused up the fire; the valve was then closed, and all communication with the external air was thus cut off. The flue was closed with an iron plate or register, that moved on a hinge. It had an opening, *c*, 8 inches square, for carrying the smoke into the chimney, and this was found large enough for a fire-place of any dimensions. This ingenious contrivance does not seem to have succeeded, although both it and the arrangement described by Savot have, with slight variations, been brought forward several times within the last three quarters of a century, and patented as notable inventions.

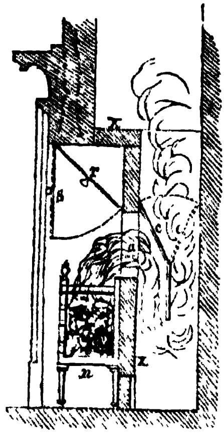
Fig. 14.



In 1678, Prince Rupert invented a fire-place, so contrived

that the draught took a downward direction before entering the flue, as shewn in Fig. 15, in which a x is a wall built at a distance of 10 inches from the back of the hearth recess, and carried up to the mantel, where it is terminated by the wall x, thus completely closing all communication between the flue and the room. An opening, a, is made in this wall, 10 inches high, and of the same width as the length of the grate, and its sill is 2 inches above the top rib of of the grate. Fixed within the chimney is a plate of iron, i, placed perpendicularly, so as to divide it into two equal parts. To the upper edge of this plate is hinged an iron door, c, as long as the chimney is wide, and this door can be brought into the position c, or into that indicated by the dotted lines at e. The fuel grate stands on the hearth, and is placed nearly in a line with the wall of the room. At the back of the ash-pit is a brick that closes the aperture through which the soot is removed. When the fire is first lighted, the smoke door, c, is pushed back, and when the draught is once established, this door is drawn forward, and the smoke being thus prevented from flowing upwards, reverberates downwards, and passes the lower edge of the division plate, i, and rises between it and the back of the hearth into the chimney flue. In boisterous weather, or with such a fire-place, in an upper room, where the chimney is short, another iron door, r, is hung under the edge of the mantel, in front of the fire-place, and extending the whole width of the opening. Its breadth varies according to circumstances, but it is made so as to reach within two inches of the upper bar of the fire-grate, when hanging in the position shewn by the dotted lines at s. This converts the fire into a furnace, and the room will, in such case, be "warmer than it would be with a fire four times the size made in a common cradell."

Fig. 15.

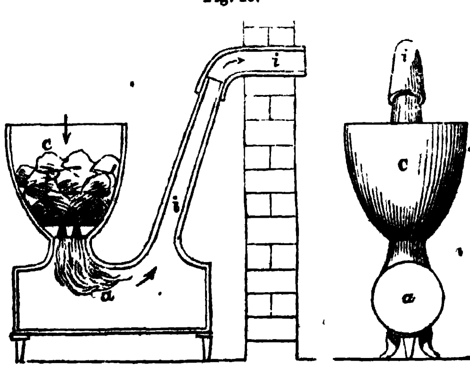


When the smoke flows regularly through the aperture *a*, this door is thrown back out of use, as at *r*. In some cases, the ordinary fire-board or *fire-cloth* was used instead of this door.

"The fire-cloth," says Mr. Bernan, "was a common appendage to a fire-place, particularly where wood was burned, for then the flue was large, the hearth wide and low, and the mantel high; when the chimney smoked in certain winds only, the cloth was suspended, when wanted, from each corner of the mantel-piece. But when the disease was unremitting, the curtain was fixed by rings, running on a rod that went across the fire-place; when not used, it was drawn to one side, like the curtain of a cottage window; very often the fire-cloth was contrived to be drawn up like a modern Venetian blind, and made so deep, as to reach from the mantel to the hearth, and serve the office of a fire-board, when there was no fire in the yawning chimney. The first variety of smoke cloth was seldom more than fifteen inches deep, and was frequently made of painted leather; but in good houses, the suspended fire-cloths were usually of damask and tapestry. None of these contrivances are yet extinct."

In 1680, a stove was exhibited at the fair of St. Germains, near Paris, in which the smoke not only descended, but was also consumed. It is formed of hammered iron, and stands on the floor of the room. The fuel, wood, or coal, is contained in a vase, *c* (Fig. 16), with a grating at *o*, and this vase is placed

Fig. 16.



on a box or cylinder *o*, from which a pipe, *i*, is carried into a flue, which has no communication with the hearth recess, nor with the air, except at the top, above the roof. The vase being filled with fuel, some dry brushwood is placed upon it. The upper part of the pipe, *i*, is then heated by a lamp, or hot iron, in order to establish a current of air from the cylinder *o*, which current passes down through the fuel in the vase. A piece of lighted paper is then placed on the brushwood, and the downward current carries the flame downwards, first igniting the wood and then the coals, and consuming the smoke in descending. The products of combustion thus carried into the cylinder, *a*, rise through the pipe, *i*, into the chimney. The descending current may be made evident by holding a flame over the vase, and it will be drawn downwards. Justel, who described this arrangement to the Royal Society in 1681, says, that "the most fœted things, matters which stink abominably when taken out of the fire, in this engine make no ill scent, neither do red herrings broiled thereon. On the other hand, all perfumes are lost, and incense makes no smell at all when burned therein." An improved edition of this stove was made by Dr. Franklin.

A very economical method of heating two rooms by one fire is described by Savot. A plate of iron is made to separate the fire-places of the two adjacent rooms. A fire made on the hearth, *a* (Fig. 17), heats the plate, and this, in its turn, by its radiation, warms the air in the adjacent room, *e*, as effectually as a stove would do, provided its flue, *i*, is properly closed. Or if the second room have no chimney, it may still be warmed by making an opening in the wall, at the back of the fire-place, and closing it with an iron plate. When Dr. Franklin was in Paris, he saw an example of this contrivance, and estimated it highly.

Fig. 17.

In all these early contrivances there is much ingenuity, and

we bring them forward thus prominently, because they are really the legitimate ancestors of many reputed modern inventions, whose authors are either ignorant of, or have failed to acknowledge, their legitimate descent therefrom. Patentees would often be spared much anxiety and expense, if they would condescend to study the subject to which their invention refers, before they introduce to the public a contrivance which may have been as well, if not better, done a long time before. Inventions, whether in the fine arts or in the useful arts, require genius often of a high order; and although it is not expected that every inventor should have the genius of Watt, it is at least required that they should possess some of his method of patient research.

But there is one writer, whose inventions have especially served as the type of many a modern fire-place, and at the time of its publication in 1713, shewed a great and sudden advance in the art of warming apartments. The author of the treatise referred to is no less a man than the Cardinal Polignac, who, under the assumed name of Gauger, published a treatise, entitled "*La Mechanique du Feu, ou l'Art d'en augmenter les effets et d'en diminuer la dépense, contenant le Traité de Nouvelles Cheminées qui echauffent plus que les Cheminées ordinaires, et qui ne sont point sujettes à fumer.*" This treatise was reprinted at Amsterdam in 1714, and a translation of it, by Dr. Desaguliers (from which we are about to quote), was published in London in 1716.

In the preface, the author has some sensible observations on the subject of warming and ventilation. After remarking that persons who judge of the value of machines by their complication, will not find his inventions to their taste, he bestows a compliment on those who estimate "such devices from the simplicity of their construction, and the facility of their execution," and then proceeds thus:—"A plate of iron or copper bowed or bended after such a manner as is not at all disagreeable to the sight; a void behind, divided by certain small iron bands or partition plates, forming several spaces

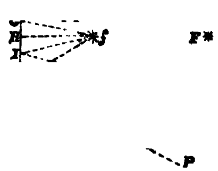
that have a communication one with another; a little vent hole in the middle of the hearth, a register plate in the upper part of the funnel; and for some shafts, a capital on the top, make up the whole construction and workmanship of our modern chimney. Now can there be anything more simple or plain, or more easy to execute?"

"To be able to kindle a fire speedily and make it, if you please flame continually, whatever wood is burning, without the use of bellows; to give heat to a spacious room, and even to another adjoining, with a little fire; to warm one's self at the same time on all sides, be the weather ever so cold, without scorching; to breathe a pure air always fresh, and to such a degree of warmth as is thought fit; to be never annoyed with smoke in one's apartment, nor have any moisture therein; to quench by one's self, and in an instant, any fire that may catch in the tunnel of a chimney; all these are but a few of the effects and properties of these wonderful machines, notwithstanding their apparent simplicity. Since I used this sort of chimney, I have not been troubled one moment with smoke, in a lodging which it rendered before untenable as soon as a fire was lighted; I have always inhaled, even during the sharpest seasons, a fresh air like that of the spring. In 1709, water that froze hard everywhere else very near the hearth, did not congeal at night in my chamber, though the fire was put out before midnight; and all that was brought thither in the day soon thawed, neither did I ever perceive the least moisture in winter, not even during thaws."

The treatise opens with the following remark:—"It seems that those who have hitherto built or caused chimneys to be erected, have only taken care to contrive in the chambers certain places where wood may be burnt, without making a due reflection that the wood in burning ought to warm those chambers, and the persons who are in them; at least, it is certain that but a very little heat is felt of the fire made in the ordinary chimneys, and that they might be ordered so as to send forth a great deal more, only by changing the disposi-

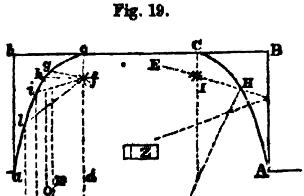
tion of their jambs and wings." The methods by which a fire may communicate its heating effect to a room, are correctly stated to be by *radiation*, by *reflection*, and by *conduction*. Now as radiant heat is reflected according to the same law as light, *i. e.*, the angle of incidence is equal to the angle of reflection, it follows that, in a fire-place with straight jambs, very few of the rays are reflected into the room. Thus, suppose a

Fig. 18



fire, *f* (Fig. 18), to be made in an ordinary chimney, A B, *b a*, of which the jambs, A B, *a b*, are parallel, the ray of heat, *f* G, will be reflected back in M; the ray *f* H upon itself in *f*; the ray *f* I in N; and the ray *f* L in P; and this is the only ray that can be reflected into the chamber, the others being to the back, or up the chimney, or among the fuel, and contribute in no way to the useful heating effect of the fire. In cases, however, where the jambs are formed of plaster, there is not even this reflection, for the heat, falling upon the dull surface, is absorbed. The author then describes what ought to be the correct form of the jambs:—"Geometricians," he says, "are sensible that all radiuses which set out from the focus of a parabola and fall upon its sides, are reflected back parallel to its axis. If, there-

Fig. 19.



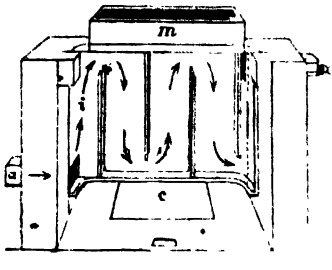
fore, you take on the bottom of a chimney hearth, A B, *b a* (Fig. 19), a length, *c* C, equal to that of the wood designed to be burnt, for example, of half a log or billet, which, at Paris, is 22 inches; from the points C *c*, let fall the perpendicular C D, *c d*, which may be the axis of two semi-parabolas, whereof C *c* are the vertices and A *a* (the distance between which is the breadth of the chimney), each of them one of their points; that done, you are to line with iron or copper plates the two parabolical sides

A C, *a c*, of the chimney, and make the lower part of the concave parallel to the horizon, and as large as it can be, only leaving ten or twelve inches for the aperture of the chimney funnel. By this arrangement, as much of the heat as can be will be reflected, for all the rays of heat from the focus F *f* of each semi-parabola, as *f g*, *f h*, *f i*, *f l*, &c., will be reflected back parallel to the axis *c d* in *m*, *n*, *o*, *p*, and consequently, pass into the room. So also, all those rays, E H I, which are not reflected back parallel to the axis, will nevertheless be reflected into the chamber or very nearly so. Besides this, the jambs being so much nearer the fire than is usual, will soon become heated, and reflect a larger number of rays."

All draughts in the room towards the fire were avoided, by introducing a *soufflet*, or blower, already described in Savot's and Winter's stoves (Figs. 12 and 14). Its opening was situated at *z* (Fig. 19), in the centre of the hearth, 10 or 12 inches below the plate on which the fuel was burned, and communicated with the open air by a channel from 4 to 6 inches square. The opening in the hearth was furnished with a metal frame, on which was hinged a trap door, or valve, opening upwards; the upper surface of this valve was furnished with a button, which could be grasped with the tongs, and a small bolt beneath could then be drawn back, or closed with the button with which it was connected. The sides of the valve were formed by two thin sectors of iron, which guided the current of air through the channel, and confined it within narrow limits. Two springs in the frame pressed against the sector sides, and kept the valve open at any desired angle; of course, when the valve was shut and bolted, there was no current.

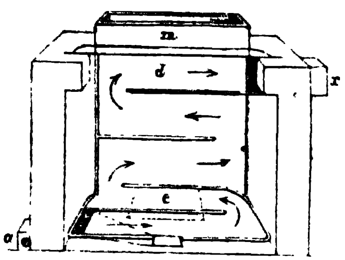
A number of complicated varieties of fire-place are described in this treatise, all of which are furnished with parabolic jambs and the soufflet; but the back, the jambs, the hearth, and the mantel, were also made hollow, for the purpose of

Fig. 20.



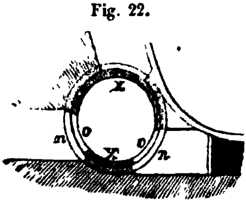
pouring a copious supply of heated air into the apartment. These hollow spaces, named *caliducts* or *meanders*, are in one arrangement (Fig. 20) formed by perpendicular divisions. In another variety (Fig. 21) they are horizontal. In this variety the hearth is also hollowed out, and divided into a series of square spaces. The cold air entering at *a*, follows the direction of the arrows, and escapes into the room at *x*; *c* is the hearth, *m* the smoke flue, and *d s i* the caliducts.

Fig. 21.



The supply of hot air, into the room was regulated by a valve in the air-channel, formed on the principle of Papin's four-way cock. A small cylinder, *x* (Fig. 22), moved within another cylinder which was fixed. The revolving cylinder had two apertures, *o o*, and the fixed cylinder three apertures. The axis of the revolving cylinder passed through the cover of the fixed cylinder, and had a small lever or needle attached to it, by means of which the cylinder was turned by the hand into certain positions marked on a small dial. When the apertures, *o o*, in the revolving cylinder coincided with those in the fixed cylinder, the external air from the channel was admitted into the caliducts in the chimney back: by turning the revolving cylinder into another position, the cold air was excluded

Fig. 22.



from the caliducts, and admitted directly into the apartments.

The cylinder could also be placed so as to shut off the cold air both from the caliducts and from the room. In this way the air of the room could be tempered according to the wants and feelings of the occupants.

The arrangement to which the Cardinal gave his decided preference, is represented in the following figures. Fig. 23

Fig. 23.

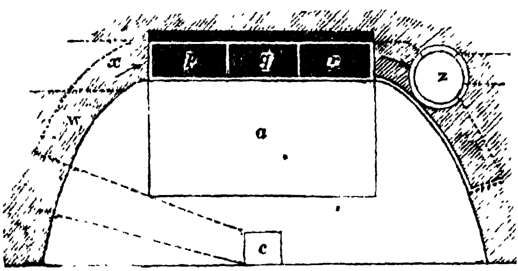
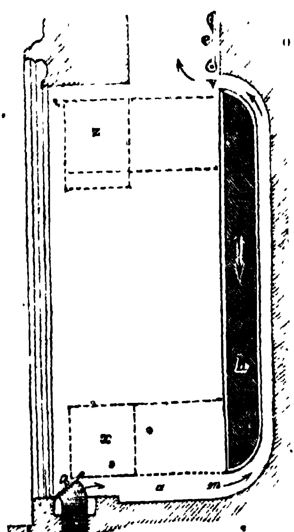


Fig. 24.



represents a horizontal section of the fire-place, and Fig. 24 a vertical section. The hollow metal case forming the back of the chimney is divided into three or more caliducts, *p q r*, each four inches wide and six inches and three quarters broad, placed about an inch from the back wall of the hearth recess, with its lower edge, *m*, about two inches above the surface of the iron bottom plate or hearth, *a*. The jambs, *w*, lined with iron or brass plates, are formed in a parabolic curve, and solid at the back. The channel, *x*, conducting the external air into the

caliducts, is nine inches on the side; and the blower, c, furnished with its valve, forms an aperture three inches long and two inches and a half wide, but instead of being supplied with air from the outside by a separate channel, the air is derived from the channel, z. The air valve, x, is placed at the junction of the cold air channel, with the caliducts; and the aperture, z, through which the warmed air enters the room, is fitted with a sliding valve, to close the warm air aperture.

The action of this apparatus is simple. The small wood on the hearth being lighted, and the valve of the soufflet, c, lifted up, the logs soon begin to kindle into a good fire; the smoke and flame rise into the space between the back, p q r, and the wall of the hearth, and, after heating the iron back of the caliducts, escape into the flue. In the meantime, the other face towards the room, is also quickly heated by the flame and smoke. The valve, o, being adjusted to admit the external air into the first caliduct, it flows thence into the second and third caliducts, receiving fresh accessions of heat in its progress, until it escapes at z, into the apartment, which it speedily warms.

For large apartments, these fire-places may be erected in the middle of the room, and two may be set back to back, with one series of caliducts for both, so that the air will be heated, whether the fire be kindled in one or both. When kindled in both, the heating effect will, of course, be greatly increased. So, also, two adjoining rooms may be heated by one fire, provided the hearth recesses are placed back to back; for, by making a fire in one room, the heated air from the caliducts may be discharged into the other; or by carrying a pipe from the caliducts through the wall into an adjoining room, or through the ceiling into an upper room, an agreeable and a sufficient warmth may be distributed.

All subsequent writers of repute have acknowledged the great merits of the Cardinal's treatise. Franklin admitted the great assistance it had afforded him; and the improvements in stoves, so successfully introduced by Count Rumford, are all similar in principle to those suggested by this book. It

will be obvious how very superior is the *Polignac fire-place* (as the arrangement just described is named), to those on the common construction, from the following remarks by Mr. Bernan:—"The external air, in passing through the caliducts, being raised to a temperate heat, and spreading itself throughout the chamber, a person in the coldest weather is surrounded with warm air, and heated, without going near the fire, on all sides at once; while, from the construction of the hearth, he enjoys the radiant heat in greater perfection than in the common chimneys. The large body of air, constantly flowing into the room from the caliducts, prevents all *chink winds* or dangerous disease-bringing currents; and as there is as much impure air withdrawn as there is fresh warm air admitted, an unceasing salutary ventilation goes on, from the time the fire is lighted until it is extinguished; so that a person may always remain in a room thus warmed, and breathe as pure an air as if he were in the fields."

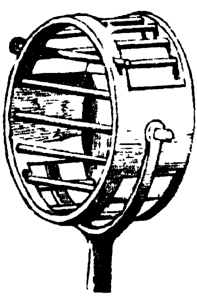
The Polignac fire-places were constructed for the combustion of wood fuel. Dr. Desaguliers modified them so as to admit of coal being burnt, and, in conjunction with an architect, manufactured them, and erected a considerable number in London. For a time the comforts and convenience, as well as economy of these fire-places, were appreciated, and they were rising rapidly into favour; but, unfortunately, an outcry was raised against them by Mr. Hauksbee and some other scientific opponents of Dr. Desaguliers, who declared that these fire-places "burnt the air, and that burnt air was fatal to animal life." This was a death blow to the Doctor's new fire-places, and many years afterwards, when referring to the subject, he mournfully remarks,—"As I took so much pains and care, and was at some expense to make this management of air useful, I can't help complaining of those who endeavoured to defeat me in it."

In 1745, Dr. Franklin introduced a fire-place, which he named the *Pennsylvanian stove,* in which Prince Rupert's descending flue was ingeniously combined with the Cardinal

Polignac's caliducts. This stove was constructed for burning wood, but in 1753, Mr. Durno adapted it for burning of coals, and sent one of his stoves to London for a model. The fuel box was 15 inches wide, 5½ inches deep, from the grating to the top bar, 5½ inches from front to back. This kept a room, 14 feet square, at a temperature of between 60° and 64° during 13 hours, with the consumption of only one peck of coals, at a time when the external temperature was 28° or 4° below freezing.

A simple, but highly ingenious grate, in which the burning fuel was made to consume its own smoke, was also one of the many original contrivances of Franklin. It consisted of a circular fire-cage, (Fig. 25,) about a foot in diameter, and from 6 to 8 inches wide from front to back; the back is of plate iron, and the front filled with bars, of which the three middle are fixed and the top and bottom moveable, and either one may be drawn out for the purpose of filling the grate with fuel. The fire cage turns upon axes, supported by a crochet, fixed on a stem, which revolves upon a pivot fixed to the hearth. The fire is lighted by withdrawing the upper bar and then placing wood and coals in the cage, as in a common grate, the bar is then replaced. So also in adding fresh fuel, the upper bar is removed and then replaced. When the grate is first lighted, a quantity of thick smoke is emitted by the fuel; but, as soon as it begins to burn well, the cage is turned round on its axes, so that the burning coals at the bottom shall occupy a position at the top. The whole is then turned round on the pivot, so as to bring the bars again in front; by this arrangement the fresh coals below the lighted fuel will gradually ignite, and their smoke, having to pass through the fire above them, will be entirely consumed. In this way the combustion is perfect, or nearly so, and this

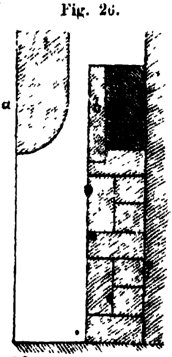
Fig 25.



economy of fuel is accompanied by a much greater heating effect; little or no soot is deposited, for all the combustible matter of the fuel is converted into heat. For want of some such contrivance, a very considerable portion of our fuel is wasted by our open fires under the best management. Soot is very inflammable, and one pound of it gives as much, if not more heat, than one pound of coal; and the quantity of soot which lines our chimneys is very inconsiderable, compared with that which escapes unconsumed at the chimney top, and fills the neighbourhood with *blacks*, and, returning into our houses through the open windows, makes the furniture dirty, or, entering our lungs, offers an impediment to free respiration. Another advantage of the revolving grate is, that it may be turned into any position, so as to radiate its heat in one direction rather than another, and, by placing the bars in a horizontal position, a teakettle, or other cooking utensil, may be conveniently set on it.

Count Rumford deserves honourable mention as an improver of grates, and an economiser of fuel. The *Rumford stove* has made his name familiar among all classes, and is so well known, that a description is unnecessary. The Count's essential improvement consisted in contracting the area of the fire-chamber, and placing a flat surface in each interior angle, as in the plan Fig. 27, so as to reflect that portion of heat into the room,

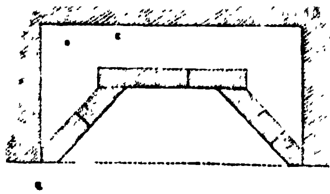
Fig. 26.



which in the old square chambered grates escaped up the chimney. The throat of the chimney was also greatly reduced in size, and the breast-work, *a* (Fig. 26), rounded off, in order to afford less obstruction to the ascent of the smoke; when the chimney required sweeping, the plate or flagstone, *b*, could be removed so as to open the throat, and be replaced after the operation. According to Rumford, in order to obtain the greatest effect from the fuel, the sides of the fire-place ought to be placed at an angle of 135° with the back of the grate, or, which is the same thing, at an angle of 45° with

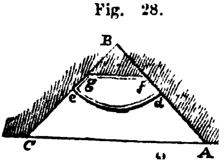
a line drawn across the front of the fire-place. (See Fig. 27.) These angular covings were not to be of iron, but of some non-conducting substance, such as fire-clay, and polished with black-lead. He objected to circular covings, on the ground that they produced eddies or currents, which would be likely to cause the chimney to smoke; and he also objected to the old form of registers or metal covers to the breast of the chimney, for the same reason; and also because by their sloping upwards towards the back of the fire-place, they caused the warm air from the room to be drawn up the chimney, and thus interfered with the passage of the smoke. These registers are now arranged so as to be lower at the back than at the front of the stove, but they are usually placed too high up. If brought down lower and placed at an angle of 45°, much of the heat of the fire would be reflected into the room. The Count also greatly diminished the size of the fire grate, and considered the best proportions for the chimney recess to be when the width of the back was equal to the depth from front to back, and the width of the front or opening between the jambs three times the width of the back.

Fig. 27.



"Although the best form for register stoves has now for several years past been adopted, the desire for novelty has caused the true principles of construction to be frequently departed from; and we accordingly find, in the most modern stoves, considerable deviations from these principles. Fig. 28 is a section of a register stove, constructed on the best possible plan for diffusing heat into the room. The sides are a right angle of 90°, A B C, and the bars, *d e*, describe a quadrant of a circle, whose radius is just half the length of the side A B. If we now wish to follow Rumford's rule of making the back one-third the width of the front, we

Fig. 28.



obtain this by taking one-third of the length A B, which will give B f; and then if we draw the line f g, we shall obtain exactly the required dimensions. By this arrangement it will be perceived, that the sides of the stove form an angle of 135° with the back; and all the rays of heat which fall upon these sloping sides, will therefore be reflected into the room, directly in front of the stove in right lines. The falling cover, or register-top should also form an angle of 135° with the back, by which a large portion of heat will be radiated downwards into the room. These proportions, however, cannot well be adopted in stoves of a very large size, as they will be found to throw the stove rather too far back; but for all moderate sized stoves, no form can be adopted which will produce so good an effect."*

We think we have now indicated all the various families of open fire-places, at least as far as their principles are concerned. The species are innumerable, and it would be impossible, in our limited space, to give even a list of them. Those who desire further information on the subject, are referred to Mr. Bernan's entertaining little volumes. But as the subject of open fires is closely connected with that of smoky chimneys, it may be useful to introduce a few details respecting this complaint and its cure.

Science often follows as well as precedes the useful arts. In the former case, she has to correct defects; in the latter case, the progress of those arts depends on her own improvement. The invention of chimneys was not a scientific result, but an act of necessity. The first object proposed to be accomplished by them was to discharge into the air the products of combustion, instead of allowing them to spread over the apartment. With the huge wood fires of our ancestors, the large hearth recess and the capacious flue did not interfere with the accomplishment of the object proposed; but as circumstances changed—when fire-places were introduced into

* *A Practical Treatise on Warming Buildings by Hot Water, &c.* By Charles Hood, F.R.S., &c. Second Edition. London, 1844.

small rooms, and coal was substituted for wood—the arrangements which were suited to the baronial hall or kitchen did not apply. Science was unable, or did not condescend, to investigate the subject, and thus the defects of chimneys continued to exist through many generations. One great defect arose from the great capacity of the flue in proportion to the extent of the fire, the heat of which was often insufficient to determine an upward current for carrying off the smoke. It is now a matter of every day experience, that the force of the draught in a chimney is so much the greater as the column of air which passes up it is longer or more heated, or, in other words, the taller the chimney, or the hotter the fire, the more rapid will be the draught. The ascentional force of this current is the difference between the weight of the column of heated air in the chimney, and a column of the surrounding atmosphere of equal height. The draught therefore is increased by increasing the perpendicular height of the chimney. Its length in a horizontal direction does not increase, but diminishes the draught, by cooling the air before it gets into the effective part of the flue. The draught is also increased, by making all the air which enters the chimney pass through or very near the fuel; for when much air gets into the chimney above the fire, by having a high mantel-piece, the mass of air in the chimney cannot get sufficiently heated.

It is a law of expansion for atmospheric air and all gases, that they dilate almost equally and very nearly in proportion to the increase of temperature. According to Gay Lussac, 1,000 cubic inches of air at the freezing temperature increase in bulk to 1,375 cubic inches at the temperature of boiling water. For an increase of temperature, therefore, from 32° to 212°, amounting to 180°, the increase of volume is 375 parts in 1,000, or $\frac{3}{8}$ of the whole bulk; and since the expansion is uniform, the increase of volume for 1° will be found by dividing this by 180, which will give an increase of $20\frac{5}{6}$ parts in 10,000 for 1° of Fahrenheit's thermometer. The recent experiments by Magnus and Regnault have thrown a doubt on

the correctness of this result. By methods perfectly independent of each other, these philosophers have arrived at 0.3665, instead of 0.375, as the true co-efficient for the expansion of atmospheric air.

Now as this law of expansion applies equally to air in motion as to air in a state of rest, we can thus calculate the amount of dilatation undergone by the column of air in a chimney from the heat of the fire in the grate. But as the heat is constantly varying, so also is the volume of ascending air. The air of the room which passes through the fire and undergoes a chemical change is intensely heated, and passing up the flue becomes reduced in temperature at every step. The air which rushes into the cavity above the fire becomes also suddenly expanded, rises, and mingling with the heated gaseous products of combustion, diminishes somewhat of their temperature, while it augments their bulk. The mean temperature of the heated ascending column may be found by taking the temperature a short distance above the burning fuel, and also at the top of the chimney; by adding these two results together, and dividing by two, we get the mean temperature, or a near approximation thereto. We are then able to calculate the force of the draught by applying one of those rules which scientific men have formed for the purpose. The method of calculation proposed by Montgolfier is very simple, and appears, from recent inquiries, to be accurate. It is this:—Ascertain the difference in height between two equal columns of air when one is heated to a certain temperature, the other being the temperature of the external air, and the force of the draught, or the rate of efflux, is equal to the velocity that a heavy body would acquire by falling freely through this difference of height.

Now the space through which a heavy body falls in perpendicular height in one second is rather more than sixteen feet; but by the law of accelerating forces, the velocity of a falling body at the end of any given time is such as would carry it in an equal time, through twice the space through which it has

fallen in that time; or the velocity, in feet per second, is equal to eight times the square root of the number of feet in the fall; or, to the square root of the number obtained by multiplying 64 by the height of the fall in feet.

When the force of the draught of a chimney is the difference in weight between two columns of air caused by the expansion of one of these columns by heat, the decimal .00208 which represents the expansion of air by 1° of Fahrenheit must be multiplied by the number of degrees the temperature is raised, and this product again by the height of the heated column. Thus if the height of the column is 50 feet, and the increase of temperature 20°, we have $20 \times .00208 \times 50 = 2.08$ feet; or 52.08 feet of hot air will balance 50 feet of the cold air; and the velocity of efflux of the heated column when pressed by the greater weight of the colder column will be equal to $8\sqrt{2.08} = 11.54$ feet per second.

The mean temperature of the heated ascending current in a chimney is much greater than 20° above that of the colder column with which it is compared; but it is most probable that air expands more proportionally at high temperatures than at low ones for equal increments of heat. As the law of expansion for high temperatures has not, as far as we know, been determined, it was thought better to select an example within the range of our knowledge, than to assume a higher temperature, which would more nearly represent the conditions of the case.

By the same means, the efflux of air, under any given pressure, can also be calculated. The pressure being known, we calculate the height of a column of air equal in weight to this pressure. Thus if the pressure be equal to one inch of mercury, water is 827 times the weight of air, and mercury 13.5 times the weight of water; therefore $827 \times 13.5 = 11,164$ inches, or 930.4 feet; and according to the rule $8\sqrt{930.4} = 244$ feet per second for the velocity of efflux under the pressure of one inch of mercury.

In these cases, however, there must be an allowance for loss

by friction, which will vary according to the nature and size of the chimney shaft, and also according to the velocity of the air. The retardation of the air by friction, in passing through straight tubes, will be directly as the length of the tube and the square of the velocity, and inversely as the diameter.

In this way the action of chimneys is brought within the domain of science. There are, however, practical difficulties and special cases which usually come under the pathological treatment of the smoke-doctor; these may all be resolved by reference to well-known scientific principles, but, unfortunately, the smoke-doctor is not always, indeed very seldom, a man of science. The following cases of smoky chimneys and the method of cure, will include as much as need be said on this subject to the intelligent reader.

Chimneys may smoke for want of a sufficient supply of air. This is sometimes the case in a new house, where doors and windows fit tightly and accurately, so that scarcely a chink is left for the admission of air. Or if the house be not new, the windows and doors are often listed, sandbags are placed over the junction of the two window-frames, and a thick mat closes the bottom of the door, and even the key-hole is often stopped. It is no wonder that, under such circumstances, the chimney should smoke; for the air necessary to support the fire must come down the chimney (the only way left for it) instead of passing through the fire and up it. To ascertain in a rough way, how much air is required per minute to make the fire burn well without smoking, set the door open until the fire is burning properly, then gradually close it until smoke again begins to appear. Then open it a little wider and hold it in such a position as will admit the necessary supply. Now observe the width of the open crevice between the edge of the door, and the rabbet into which it would shut. Suppose this distance to be half an inch in a door eight feet high; the room would, in such case, require for the entrance of the air an aperture equal to 48 square inches, or a hole six inches by eight inches. This however would be more than is usually required. Dr.

Franklin found that a square opening of six inches to the side, was a good medium size for most chimneys. But now comes the difficulty (at least in English houses, where no air duct is provided by the architect and builder, as in the Polignac fire-place), where to make this opening. If made in the door, it not only interferes with the privacy of the room, but admits of cold draught to the back and feet of those sitting near the fire; if made in the window, it brings a cataract of cold air down upon the heads of the inmates.

It has been proposed to cut a crevice in the upper part of the window frame, and to place below this a thin shelf, sloping upwards, in order to direct the air towards the ceiling, where mingling with the heated air of the apartment, it would mitigate its temperature, and bring it down again to feed the fire. The objection to this plan is, that it would cool the room; but as fresh air admitted from any other source would have a similar cooling effect, it is not easy to propose a better plan. An old fashioned contrivance for kitchens was to place in one of the spaces of the window-frame a circular tin plate, containing a wheel mounted on an axis, the radii or vanes being bent obliquely; these being acted on by the entering air, forced it round like the vanes of a windmill, and at the same time dispersed the air to a certain extent, and prevented a distinct draught from being felt. Another method was to take out a pane of glass and substitute a tin frame, giving it two springing angular sides, and being furnished with hinges below, it could be drawn in more or less above, so that the incoming air might be directed upwards, and regulated as to quantity. A contrivance has lately been introduced for ventilating rooms, but when there is a fire in the room, it must serve the purpose of introducing air instead of letting it out. It consists of a number of strips of plate glass, arranged after the fashion of a Venetian blind, occupying the position of one of the panes of glass in the upper window frame. By a little adjusting motion, the strips can be separated more or less apart, to regulate the supply of air, or closed entirely, so as

to exclude it. Perforated panes of glass have also been introduced as ventilators, but they must also bring air into the room instead of letting it out, when a fire is burning.

A second cause of smoky chimneys arises from the size of the fire-place; it may be too wide or too high. Dr. Franklin recommended that the openings in the lower rooms should be about 30 inches square and 18 deep; and those in the upper rooms only 18 inches square and not quite so deep; the intermediate openings diminishing in proportion to the height of the funnel.

But the funnel itself may be too high compared with the size of the fire. The hot air ascending to a certain height may distribute its heat to the air in the upper part of the flue, so that the whole may cool down, and the column within the flue be nearly of the same weight as an equal column on the outside. In such a case, there will be little or no draught to carry off the smoke, and it will, therefore, enter the room.

But it more frequently happens that the funnel is too short. The remedy in such case is to contract the opening of the chimney, so as to force all the air that enters to pass through or very near the fire.

In some houses, instead of having a separate chimney for each room or fire-place, the flue is bent or turned from an upper room into the flue of another fire from below. In such a case, the upper chimney is too short, since the length can only be estimated from the place where it enters the flue of the lower room; and this, in its turn, is also shortened in efficient length by the distance between the entrance at the second funnel and the top of the stack; for all that part being supplied with air from the second funnel, adds no force to the draught; and if there is no fire in the second chimney, it cools the hot current of the first, and so diminishes the draught. The remedy in this case is to close the opening of that chimney in which there is no fire.

Chimneys often overpower each other, and so cause them to smoke. If, for example, there are two fire-places in one

large room with fires in each, and the doors and windows closed; if the two fires do not burn equally well, either from not being lighted at the same time, or not equally supplied with fuel, or from any other cause, the stronger fire will overpower the weaker, and draw the air down its funnel to supply its own demand. The air descending the funnel of the weaker fire brings the smoke with it, and thus fills the room. Two chimneys in different rooms, which communicate by a door, may also act in this way whenever the door is opened; so, also, in a house where all the doors and windows fit tightly, a strong kitchen chimney on the lowest floor may overpower any other chimney in the house, and draw air and smoke into the rooms as often as a door communicating with the staircase is opened. Dr. Franklin mentions the case of a nobleman's house in Westminster afflicted with this troublesome complaint. It was a new house, and after the owner had paid for it, and discharged all claims, he had to expend £300 more before the smoky chimneys were cured. Of course, the only remedy for this disorder is, to provide each room with the means of furnishing the fire-place with a sufficient supply of air for the combustion of the fuel. When will architects and builders be convinced of the fact, that fire-places, as well as human beings, require constant supplies of fresh air, and that it is their duty to provide every room with air channels, placed so as to feed the fire without annoying the inmates?

Another fruitful source of smoky chimneys is, when their tops are commanded by higher buildings, or by a hill, so that the wind blowing over them, falls like water over a dam, sometimes almost passing over the tops of the chimneys, and beating down the smoke. If the funnels cannot be raised, so that their tops may be of the same height or higher than the eminence, the only remedy is to mount one of those ugly contrivances with which the chimney doctors delight to satirise the architect and builder, and which are thus enumerated by an amusing writer in Chambers's *Edinburgh Journal*:—" The simplest of all consists in the well-known

revolving bonnets or cowls, with wind-arrows on their summits; which, by the way, were once called Bishops in Scotland, while a friend assures me, that in the west of England he has heard them styled Presbyterians. The philosophy of this contrivance is sufficiently simple, in whichever direction the wind blows, the mouth of the chimney is averted from it. This principle has its development in a thousand devices—some looking like Dutch ovens come up to see the world, some like half sections of sugar loaves, some like capital H's, and sundry other pleasing objects. The red chimney-pots, too, have contrivances of a similar intention, in the diverging spouts and cavities and twists which some of them delight in. A different species, is the perforated whirling variety, which seem perpetually whizzing round for the mere fun of the thing, since any good they do is extremely apt to escape detection. They are a lively-looking apparatus; but on squally nights, and when the pivot becomes a little rusty, the musical sounds they give forth can scarcely be considered agreeable. Among the more ingenious of smoke-curers, an invention of recent origin, named the *Archimedean screw ventilator* deserves a place. It consists, as its name implies, of wind-vanes attached to the extremity of a revolving screw. When the wind strikes these vanes, it produces a rapid revolution of the screw, which is thus supposed to *wind up* the smoke or vitiated air from below. Perhaps it serves the proposed end; but whether the positive advantage thus gained is not lost by the obstruction of such apparatus to the free passage of smoke in calm weather, is a point, in my estimation, more than questionable. For the relief of such chimneys as only smoke in windy weather, perhaps, this and other forms of external apparatus are best adapted. Another invention of equal merit, is a chimney-cap of metal externally grooved in a series of spiral curves up the pipe, which end in a kind of mouth-piece, from whence the smoke issues. The wind, when impelled against this apparatus, is supposed to take somewhat of the direction of the spiral grooves, and

thus to form an upward current to assist the emission of the smoke." One of the most recent of this class of inventions is *Day's wind-guard*, which consists of an octagonal metallic chimney-cap, having four slits in it, which are protected by projecting pieces or slips of metal. When a current of air strikes in any direction against the cap, it reflects or turns the air in such a manner, as immediately to produce a draught up the pipe. "In casting one's eye down the long streets of the smoky city, in taking a survey of the roofs and their tormented chimneys, the infinity of other contrivances is so great, that it is scarcely a poetical hyperbole to say our pen starts back from it. Here is patent upon patent, scheme after scheme, each doing its best, no doubt, to obtain the mastery over that simple thing—smoke; and each with a degree of success of a very hopeless amount. There appears to me something intensely ludicrous in these struggles against what seems to be an absurd, but an invincible foe; the very element of whose success against us lies in our not strangling him in his birth. Many obstacles are in the way, no doubt; there are obstacles in the way of every good; but I have little doubt, that had the perverted ingenuity which has mis-spent itself upon the chimney-pots been directed to the fire-place, we might have now had a different tale to tell. The smoke nuisance is laughed at as a minor evil, by a great practical people like ourselves, who heroically make up our minds to put up with it; but when it is considered as an item in the comfort, cleanliness, and health of a whole nation, it assumes, or should assume, a different position."

We do not by any means affirm that the above contrivances are always effectual in the cure of smoky chimneys; for it is easy to imagine cases where chimneys will, or rather must smoke, in spite of the whole host of caps, cowls, and vanes. For example, when a commanding eminence is farther from the wind than the chimney commanded, the wind would, as it were, be dammed up between the house and the eminence, and force its way down the chimneys in whatever position the

turn-cap or other contrivance might be situated. Dr. Franklin, mentions a city in which many houses were tormented with smoky chimneys by this operation, for their kitchens being built behind, and connected by a passage with the houses, the tops of the kitchen chimneys were thus lower than the tops of the houses, and thus, when the wind blew against the backs of the houses, the whole side of a street formed a dam, and the obstructed wind was forced down the kitchen chimneys, and passed along the passages into the houses, and so into the street. This was especially the case when the kitchen fires were burning badly. In summer, the annoyance assumed a different form, for the smoke was wafted from the kitchen chimneys into the chambers of the upper rooms.

Chimneys, which otherwise draw well, will often smoke from the improper situation of a door. Thus when the door and the chimney are on the same side of the room, and the door, being in the corner, is made to open against the wall, as is usually done, to have it more out of the way, it follows that, when the door is partially opened, a current of air rushes in and passes along the wall into and across the opening of the fire-place, and whisks the smoke into the room. This happens more frequently when the door is being shut, for then the force of the current is increased, and persons sitting near the fire feel all the inconvenience both of the draught and the smoke. A remedy may be found by an intervening screen, projecting from the wall and passing round a great part of the fire-place; or still better, by shifting the hinges of the door, so as to throw the air along the other wall.

A room with no fire in it is sometimes filled with smoke from the funnel of another room, in which a fire is burning. This arises from changes in density of the air in the cold funnel, from changes in temperature by day and by night, as well as from changes in the direction of the wind. It is found that when the temperature of the outer air and of that in the funnels is nearly equal, the air begins to ascend the funnels as the cool of the evening comes on, and this current will continue

till nine or ten o'clock next morning ; then, as the heat of the day approaches, it sets downwards and continues to do so till evening ; it then changes again and continues to go upwards during the night. Now when the smoke from the tops of neighbouring funnels passes over the tops of funnels which are drawing downwards, the smoke is also drawn down and descends with the air into the chamber. The remedy proposed by Dr. Franklin, was to contract the opening of the chimney to about two feet between the jambs, and to bring the breast down to about three feet of the hearth. An iron frame is then placed just under the breast, and extending to the back of the chimney, so that a plate of iron may slide horizontally backwards and forwards in the grooves on each side of the frame : this plate, when thrust quite in, fills up the whole space, and shuts up the chimney entirely when there is no fire. But when there is a fire, it can be drawn out, so as to leave between its further edge and the back, a space of about two inches, which is sufficient for the smoke to pass ; and so large a part of the funnel being stopped by the rest of the plate, the passage of warm air out of the room up the chimney is in great measure prevented, as is also the cold air from crevices to supply its place. The effect is seen in three ways :—1, When the fire burns briskly in cold weather, the howling or whisking of the wind, as it enters the room through the crevices when the chimney is open, ceases as soon as the plate is slid in to its proper distance. 2, Opening the door of the room about half an inch, and holding the hand against the opening near the top of the door, you feel the cold air coming in against your hand, but weakly if the plate be in. Let another person draw it out, so as to let the air of the room go up the chimney with its usual freedom in open chimneys, and you immediately feel the cold air rushing in strongly. 3, If something be set against the door, just sufficient when the plate is in to keep the door nearly shut, by resisting the pressure of the air that would force it open, then, when the plate is drawn out, the door will be forced open by the increased pressure of the outward cold air endeavouring to

get in, to supply the place of the warm air that now passes out of the room to go up the chimney. "In our common open chimneys," says the Doctor, "half of the fuel is wasted, and its effect lost; the air it has warmed being immediately drawn off."

The form of the chimney-pot has also an influence on the free passage of the smoke. Many of those fancy chimney-pots ornamented, singly or clustered together, will cause the chimneys to smoke in strong winds; the ornaments serving as points of resistance to the wind, after reflecting it down the chimney; and the clustered arrangement presenting a broad resisting surface, so that the wind, in blowing against them, rises up along the surface, and blows strongly over the mouths of the pots, so that the smoke cannot force its way through the blast. In Venice, the top of the flue is rounded into the true form of a funnel, and this is often found to answer the purpose; but, at present, we do not know of any remedy except a turn-cap, or one of the many elegant contrivances which give such wonderful variety to the sky line of most of our houses and public buildings.

Cases of smoky chimneys may arise, which may puzzle the science of the most accomplished smoke doctor. We borrow two such cases from Franklin. "I once lodged," he says, "in a house in London, which, in a little room, had a single chimney and funnel. The opening was very small, yet it did not keep in the smoke, and all attempts to have a fire in this room were fruitless. I could not imagine the reason; till at length, observing that the chamber over it, which had no fire-place in it, was always filled with smoke when a fire was kindled below, and that the smoke came through the cracks and crevices of the wainscoat. I had the wainscoat taken down, and discovered that the funnel which went up behind it, had a crack many feet in length, and wide enough to admit my arm; a breach very dangerous with regard to fire, and occasioned, probably, by an apparent irregular settling of one side of the house. The air entering this breach freely, destroyed the drawing force of the funnel. The remedy would have been, filling up the breach,

or rather rebuilding the funnel; but the landlord rather chose to stop up the chimney."

The second case occurred at the house of a friend near London: "His best room had a chimney, in which he told me he never could have a fire, for all the smoke came out into the room. I flattered myself I could easily find the cause, and prescribe the cure. I opened the door, and perceived it was not want of air. I made a temporary contraction of the opening of the chimney, and found that it was not its being too large that caused the smoke to issue. I went and looked up at the top of the chimney, its funnel was joined in the same stack with others, some of them shorter, that drew very well, and I saw nothing to prevent its doing the same. In fine, after every other examination I could think of, I was obliged to own the insufficiency of my skill. But my friend, who made no pretension to such kind of knowledge, afterwards discovered the cause himself. He got to the top of the funnel by a ladder, and looking down, found it filled with twigs and straw cemented by earth, and lined with feathers. It seems, the house, after being built, had stood empty some years before he occupied it; and he concluded that some large birds had taken the advantage of its retired situation to make their nests there. The rubbish, considerable in quantity, being removed, and the funnel cleared, the chimney drew well, and gave satisfaction."

It has been remarked, that chimneys situated in the north wall of a house, do not draw so well as those in a south wall; because when cooled by north winds, they are apt to draw downwards. Hence, chimneys enclosed in the body of a house, are more favourably situated than those in exposed walls. Chimneys in stacks often draw better than separate funnels, because those that have constant fires in them warm those in which there are none.

We have devoted a considerable space to this subject, because we think the reader has a right to expect, in a practical book of this kind, tolerably full information on a subject, in which

all are interested; and the above cases seem to include most of the causes of smoky chimneys and their remedies. The open fire-place is so intimately connected with an Englishman's ideas of domestic comfort, that it can never be expected, while coals are plentiful, that a more economical method of warming our rooms will become very common. It is, therefore, the duty of scientific men, to make the open fire-place as comfortable as it certainly is wholesome, and if a better method of supplying air to the fire than the present chance arrangement were adopted; if caliducts were led round the fire, so as to discharge warm air into distant parts of the room, and even over the house; if the various parts of the fire-place were of the proper shape and dimensions; there seems to be no good reason against retaining our cherished open fire, and converting it from a troublesome, uncertain, smoky, and expensive companion, into a source of health, pleasure, and economy.

CHAPTER II.

ON THE METHODS OF WARMING BUILDINGS BY MEANS OF CLOSE STOVES AND HOT-AIR APPARATUS.

ONE of the most intelligent advocates* in the cause of the CLOSE-STOVE *versus* the OPEN FIRE-PLACE, has preferred a very serious bill of indictment against the defendant. It consists of no less than eleven counts, of which the following is a summary. I. *Waste of fuel.* Of the whole heat produced from the fuel used, about seven-eighths ascend the chimney and are wasted. The loss of heat is first, more than half, which is in the smoke as it issues from the burning mass. Secondly, that carried off by the current of the warmed air of the room,

* Dr. Arnott. "*Warming and Ventilation, with Directions for making the Thermometer Stove, &c.*" London, 1838. The writer wishes to acknowledge his obligations to this excellent little treatise.

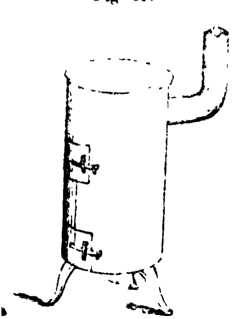
which is constantly entering the chimney between the fire and the mantel-piece, and mixing with the smoke. This is estimated at nearly two-eighths. Thirdly, the soot, or visible part of the smoke, is unburned fuel, and if more than half of the heat produced be in the smoke, and nearly a fourth of it in the warm air from the room which escapes with the smoke, and if about an eighth of the combustible pass away unburned, there is a loss of at least seven-eighths of the whole. Count Rumford estimated the loss at fourteen-fifteenths. These estimates must of course be supposed to refer to the open fire-place with square jambs. II. *Unequal heating at different distances from the fire.* As the intensity of radiant heat is only one-fourth as great at a double distance, and so on, its effect being inversely as the square of the distance, the walls of the room are scarcely heated, and therefore reflect no heat to persons round the fire. There is usually one circular line around the fire in which persons must sit to be comfortable; and within this line they are too hot, and beyond it too cold. III. *Cold draughts* from doors and windows. IV. *Cold foot-bath.* The fresh entering air, being colder than the general mass already in the room, occupies the bottom of the apartment, and forms a dangerous cold air-bath for the feet of the inmates, so that they must keep their feet raised out of it by foot-stools, or wear warmer clothing. We see how anxious cats are to get out of this cold air-bath by occupying the seats of chairs, &c., instead of the carpet. V. *Bad ventilation.* The heated respired air ascends to the ceiling, and, getting cool, descends, and is breathed over again; or, if the fire be not sufficiently supplied with air from the door and windows, it will come from other quarters, and bring in foul air from drains, &c. VI. *Smoke and dust.* VII. *Loss of time* in lighting the fires in the morning, and again during the day if neglected and allowed to go out. VIII. *Danger to property.* In London alone there are, at an average, 140 fires per month. IX. *Danger to the person.* Children get burnt, and the dresses of ladies sometimes take fire by a sudden draught

from the door, or coming too near the fire. X. *Expense of attendance.* It is contended that servants have more work to do in houses with open fires, than where stoves are kept. XI. *Necessity of sweeping-boys.*

This is certainly a formidable indictment, but after the details given in the last chapter, it is not necessary to enter upon any further defence. There is no doubt that, upon some of the counts, the defendant must be found guilty; but it will be seen, in the present chapter, that the plaintiff does not come into court with clean hands, for there are many objections to the close stove, from which the open grate is entirely free. These will be stated as we proceed.

The close stove is used chiefly in those countries where fuel is scarce. One of the simplest forms is the *Dutch* stove, shewn in Fig. 29. The fuel rests on the bars of a grate, near the bottom, and the air enters below the grate. The fuel is introduced by a door above the grate, which door is closed while the stove is in action, and as this is the only opening in the stove above the fuel, no air can reach the chimney, except that which has passed through the fire, thus saving the waste of warm air, which, in open fires, passes between the fire and the mantel-piece. The heating effect of this stove is due to the whole surface of the stove, and its flue receiving the direct heat of combustion, as well as much of the heat of the products of combustion, as they escape into the chimney, and, if the flue be made sufficiently long, so as to expose a large surface in the room, nearly the whole of the heat may be applied to use, without draughts, or smoke, or dust. These are the good qualities of the Dutch stove; now for its bad ones. The heated iron surface acts upon the air in contact with it, so as to impair its purity and fitness for respiration. "The air," says Dr. Arnott, "acquires a burnt and often sulphurous

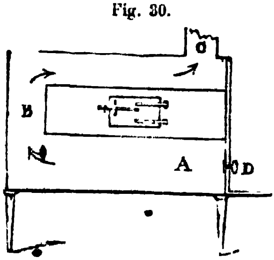
Fig. 29.



smell, in part, no doubt, because dust, which it often carries, is burned, and, in part, because there is a peculiar action of the iron upon the air. It becomes very dry, too, like that of an African simoom, shrivelling everything which it touches; and it acquires probably some new electrical properties. These changes combined make it so offensive, that Englishmen, unaccustomed to it, cannot bear it. In this country, many forms have been proposed, some of them gracefully designed, with transparent talc doors, and other attractions; and they have been tried in rooms, public offices, passages, halls, &c., but have been afterwards very generally abandoned. Persons breathing the air heated by them, are often affected by headaches, giddiness, stupor, loss of appetite, ophthalmia, &c. A north-east wind, which distresses many people, bringing asthmas, croups, &c., and which withers vegetation, is peculiar chiefly in being dry." This stove is much used by laundresses and others for drying, and in this application of it, the doctor admits, it is good and economical. The ornamental varieties of it are also furnished with vases and other receptacles for water, which, by its evaporation, greatly mitigates the evils complained of; but it must be admitted, that the list of objections brought against the Dutch stove forms as formidable a bill of indictment as that preferred against the open fire. Another objection not noticed in the above quotation, arises from the overheating of the flue. It has often been known to get red-hot, and has thus led to serious conflagrations.

The American stove is a square close iron box, with a vessel of water upon it, to give moisture to the air. It has a plate

Fig. 30.



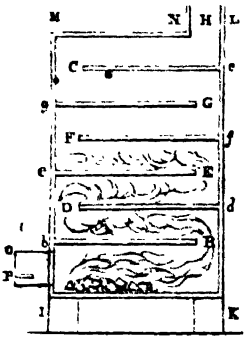
projecting under the door, D (Fig. 30); the wood fuel is burned within at A, and the flame passes along by B, to the chimney, C, around an inner box, which is the cooking oven of the family, opening by a door in the side of the stove. The fuel is introduced by

a large door at D, in which there is a smaller door, which, as well as the larger, is usually kept shut, because a sufficient supply of air enters by the joinings around; but in cold weather, the small door is opened to increase the combustion. The stove has iron legs, about a foot in length.

In Russia, Prussia, and the North of Europe generally, the stove is a very important article of domestic furniture, in which the largest possible amount of heating effect is obtained from the smallest possible quantity of fuel. In the construction of these stoves, the following points are kept in view :—To maintain in the fire-place the high temperature necessary for the perfect combustion of the fuel, by surrounding it with such substances as are bad conductors of heat, such as fire-stone or bricks; to have the means of regulating the quantity of air admitted to the fuel, by valves in the doors which enclose the ash-pit and fire-chamber, and by accurate fitting of the doors and valves themselves. Thirdly, to bring all the gaseous products of combustion, as they escape from the fuel, into contact with the largest possible area of slowly conducting surface, so as to maintain it at an equal temperature; and, lastly, to make the smoke enter the chimney with the smallest velocity, or lowest temperature, that is practically consistent with the first condition. In no case, should this temperature exceed 150°, nor should the metallic surface ever be raised higher than 100°, nor the stream of air issuing from it exceed 70°. In every case, the combustion is regulated by limiting the supply of air, and if the heating surface be small, the fire is reduced so as to produce no more heat than can be carried off by the radiation and conduction of such heating surface.

The method in which these conditions are complied with, will be understood by referring to Fig. 31, which represents a general form of stove. It may be modified according to circumstances of utility or taste, but the principle is the same in all. M I K L is a quadrangular box of any size, in the directions M I L K; but the inside width, from front to

Fig. 31.



back, is generally pretty constant; it is never less than 10 inches, and seldom extending to 20 inches. The whole included space is divided by a number of partitions. The lowest chamber, B, serves for the fuel, which is placed on the bottom of the stove without any grate. The fire-place has a door, O, turning on hinges, and in this door is a small wicket, P. The roof of the fire-place extends to within a very few inches of the further end, having a narrow passage, B, for the flame. The next partition, *d*, is about eight inches higher, and reaches almost to the other end, leaving a narrow passage for the flame at D. The partitions *e f g c* are repeated above at the distance of eight inches, leaving passages E F G C at the ends alternately disposed, the last communicating with the vent in the H flue. This communication is regulated by an iron plate, or damper, N L, which can be slid across it by moving a rod, which passes out through the side. If the fuel be wood, as is generally the case, and the vent opens into the room, this passage is closed by a sort of pan, or bowl of earthenware, which is inverted over it, with its brim buried in sand, contained in a groove formed all round the hole. The whole stove is set on low pillars, so that its bottom may be a few inches from the floor of the room. It is usually placed in a corner of the apartment, which is so disposed that the chimneys can be joined in stacks, as with us. In lighting the stove, straw or wood shavings are first burnt on the hearth at its farther end, in order to warm the air in the stove and determine a current. The fuel is then laid on the hearth close by the door, and piled up and kindled, and the current, being already directed to the vent, there is no danger of smoke getting out into the room. The door, O, is then closed and the wicket, P, opened, and the air supplied by

this means, being directed to the middle or bottom of the fuel, it is quickly kindled and is soon burning well.

Now it will be seen, by this construction, that the flame, and heated products of combustion are retained as long as possible within the body of the stove, and their heat diffused over a very extended surface, which is still further increased by making the stove narrower from front to back in its upper part. A certain breadth is necessary below, that there may be room for the bulky wood fuel; but if this breadth were preserved all the way up, much heat would be lost, because the heat, communicated to the partitions of the stove, acts with little or no useful effect, so that, by diminishing their breadth, the proportion of heating surface is increased. The whole body of the stove may, as Professor Robison remarks, be considered as a long pipe folded up, and its effect would be the greatest possible, if it really were so, that is, if each partition were split into two, and a free passage allowed between them for the air of the room.

In order that the heated surface may be as extensive as possible, the stove is not built into the wall, nor in contact with it, or with the floor. By being thus detached, both the back and bottom of the stove are sources of heat to the air of the room, and the bottom, which is the hottest part, contributes at least half the heating effect. Sometimes, however, the stove forms a part of the wall between two rooms, and serves to heat both. It is also common to have the door of the fire in the passage on the outside of the room, so that an attendant can manage it without incommoding the occupants.

The author of *A Residence on the Shores of the Baltic*, 1841, refers to these stoves in the following terms :—"Within these great houses, not a breath of cold is experienced. The rooms are heated by stoves, frequently ornamental rather than otherwise; being built in tower-like shapes, story over story, of pure white porcelain, in various graceful architectural mouldings; sometimes surmounted with classic figures of great

beauty, and opening with brass doors, kept as bright as if they were of gold. In houses of less display, these stoves are merely a projection in the wall, coloured and corniced in the same style as the apartment. In adjoining rooms they are generally placed back to back, so that the same fire suffices for both. These are heated but once in the twenty-four hours by an old caliban, whose business during the winter it is to do little else. Each stove will hold a heavy armful of billet, which blazes, snaps, and cracks most merrily; and when the ashes have been carefully turned and raked with what is termed an *ofen gabel*, or stove fork, so that no unburnt morsel remains, the chimney aperture is closed over the glowing embers, the brass doors firmly shut, and in about six hours after this, the stove is at the hottest—indeed, it never cools."

The useful effect of this stove depends very much on retaining in the room the air already heated by it. A small open fire in the same room will actually diminish the heating effect of the stove, and even draw the warm air from adjoining apartments. In the houses of English merchants at St. Petersburg, open fires are sometimes introduced into rooms with stoves; and the consequence is, that it is found necessary to light the stoves twice a day, and yet the houses are cooler than those of the Russians, who light them only once. To our notions, however, a cool in-door atmosphere is preferable to a nauseous stagnant one, such as the Russians and Germans are accustomed to breathe throughout the winter; and even in summer, they are very averse to an open window. The temperature of the winter apartments is kept nearly always at 65°, and as every part of the room is equally warm, the inmates have no occasion to crowd round the stove as we do round the fire. "But I can testify," says Dr. Buxton, "that in German rooms there is a closeness of feeling to a person accustomed to free air, which is unpleasant, if not unwholesome—no change of air, the windows closed as tight as can be, and the door fits as exactly as the carpenter can make it. The stove is air-tight with regard to the room, and there is

nothing to occasion a current like an English open fire. The apartments of the sick almost invariably smell disagreeably. I do not, however, recollect seeing a single ventilator in Germany; but I have repeatedly seen double windows." As ventilation can only be procured at the expense of heat, the people prefer retaining the foul air to expending an extra portion of fuel. In the houses of the poorer classes in Russia, where the windows are single, and a number of persons occupy a small stove-heated room, a thick icy crust forms on the inside of the windows during frosty weather, arising from the condensation of the breath, perspiration, and the aqueous fumes of candles, and of the stove, &c. When a thaw comes on, this icy crust is converted into water, and a deleterious principle is disengaged, which produces effects similar to those arising from the fumes of charcoal. Persons so affected are immediately carried into the open air, and placed on the snow with very little clothing; the temples and the region of the stomach are well rubbed with snow, and cold water is poured down their throats, and the friction is continued until the livid hue of the skin disappears, and the natural colour is restored. The Chinese are wiser in this respect than the Russians, for, although their rooms may in winter be as hot and as crowded, they have two openings at the top of each window, which are never allowed to be closed, and through these ventilation is carried on.

The stove last described belongs rather to that variety called the *Swedish stove*, than to the *Russian* or *German*. In the Russian or German stove, the smoke, after rising from the fuel, recedes into the flue, and becomes cooled by contact with the walls of the circulating chambers, and the heat is by this means retained in the apartment which would otherwise have escaped combined with the vapour. In the Swedish stove, the circumvolutions of the smoke are exposed to a vivid heat, so that every particle of soot undergoes a second combustion in the circulating channels. Some of the Swedish stoves have from four to nine channels for the circulation of the smoke;

some are contrived to receive one or more boilers, and others to act as ovens; and they all greatly economise the fuel, for, according to Morveau, the quantity of wood which is consumed in twenty-three days in an open fire, with less effect, will last sixty-three days in a stove.

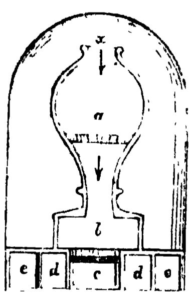
In erecting the ponderous German stoves, it is necessary to arrange the various pieces of clay, or porcelain, so that no part should crack or give way, and thus admit the smoke or carbonic acid vapour into the room. When the parts are put together with cement, or held by iron cramps, a leakage commonly occurs at the joinings, where the different pieces of clay are differently heated, and, perhaps, were of a different baking when made; hence, by expanding unequally and working on each other, one of them must give way. But instead of making the joints close and using any cement, the best method is to make each upper piece stand in a groove formed in the piece below it, and then to sprinkle a little powdered chalk or clay over it, which will effectually prevent the passage of any air, and, at the same time, allow space for any expansion or contraction at the joint.

Some valuable experiments by Mr. Bull are quoted by Mr. Bernan, to shew the effect of ascending and descending flues in the Russian and Swedish stoves, and of elbows or bends in the flue of the common Dutch stove. From these experiments, it appears that the same length of pipe is much more efficacious in imparting heat to a room when it has elbows than when it is straight; that a descending current may be somewhat more efficacious than an ascending one, but is about equal with a horizontal one; a horizontal pipe, with the same number of elbows, is more efficacious in imparting heat, than when placed vertically for an ascending and descending current. The cause of the increased effect is supposed to arise from the shape of the pipe forcing the heated air to make abrupt turns; in doing which, it impinges against the elbows with sufficient force to invert its internal arrangement, by which a new stratum of hot air from the interior

of the current is brought more frequently in contact with the sides of the pipe, and particularly with the lower half of the horizontal pipe, which, from various causes, gives out very little heat to the room, without the aid of elbow joints. But the advantage gained by increasing the length of pipe and number of joints, has a limit very far short of that which is found to be necessary to impart all, or the greatest part, of the heat generated to the air of the room. Only five parts of heat in 100 were lost by using 13½ feet of pipe, consisting of nine elbow joints; whereas, eight additional elbow joints, and 16½ feet additional of straight pipe, in all 28½ feet of pipe, were required to save these five parts, and prevent their flowing into the chimney. By diminishing the diameter of the pipe, the heating effect is increased, partly from the retardation of the current, and partly from the small pipe exposing a greater surface to the air with the same quantity of smoke than a pipe of larger diameter.

An excellent stove with a descending current was constructed by Dr. Franklin, for his own use. Fig. 32 represents

Fig.



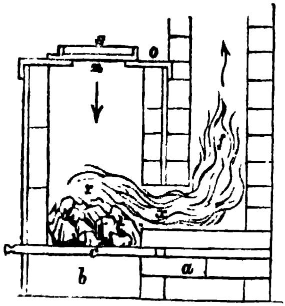
a vertical section, in which x is an opening in the cover, furnished with a hinge; a is a fire-chamber, in which the grating is fixed; b, a space containing a second grating; c, the ash-pit, with a drawer to receive the ashes; d e, horizontal flues at each side of the ash-box, communicating with vertical flues which lead into the chimney. The vase and flues are contained in a niche formed by closing up the fire-place, and there is no communication between the room and the flue, except through the opening x in the lid. The fire is first lighted between 8 A.M. and 8 P.M., when there is usually a draught *up* the chimney, as already explained (page 91); but the direction of the draught had better be ascertained by holding a flame over the air-hole at the top of the vase. If the flame be drawn strongly

down, the fire may be lighted by first putting in a little charcoal on the grate at *a*; then lay some small sticks on the charcoal and some paper on the sticks; set light to the paper and shut down the lid; the air will pass down through the air-hole, and blowing the flame of the paper through the sticks, kindle them, and they, in their turn, will kindle the charcoal. The flame and hot vapour descending through the grating at *a*, passes into the chamber *b*, and through the second grating in its bottom into the ash-pit, *c*. The hot current will then be divided—one portion turning to the left, and passing into the horizontal channels *d*, *e*, and entering the vertical flue, will be conducted into the chimney; the other portion will make a similar circuit on the left in the channels *d c*, and entering another flue, will in like manner pass into the chimney. The surfaces of the vase and air-box, and the part of the horizontal channels exposed to the room, are heated by these circumvolutions of the vapour, and the air warmed by contact with them, spreads into the room. The larger pieces of coal that fall through the grating on the vase, are caught by the second grating, *b*, and the ashes fall through it into the ash-pit box, *c*. The success of this excellent contrivance depends of course upon maintaining an upward steady draught in the chimney flue, so that the ash-pit drawer and a door in the chamber *b*, to withdraw the cinders, must be made air-tight. In order to determine an upward current on lighting the fire, a small door may be made in the side of the flue, and a piece of lighted paper inserted.

Mr. Beaumont's stove also acts by a downward current. It is represented in section, in Fig. 33. The foundation, *a*, is of bricks, two courses high, and 25 inches square, with a vacant space six and a half inches wide, for the ash-hole, *b*. Upon this foundation are laid two plates of cast iron, *c*, each, 9 inches wide, 25 inches long, and an inch thick. The plate which covers the ash-pit draws out, and in doing so, turns the ashes into the ash-pit. On these iron plates is erected a drum with an aperture, *x*, for the smoke flue. This aperture, when lined with fire

bricks, is six inches wide, and four and a half inches high. The drum is also lined with fire-bricks, set on edge, and is covered with a circular plate of cast iron, *s n*, with a downward lip round the edge, to receive the upper edge of the drum. In the middle of the cover, *n*, is a hole, seven inches in diameter, for the admission of fuel, and this is covered with a lid, moving on a pivot to regulate the admission of the air. An opening of an inch is usually sufficient for that purpose. A short

Fig. 33.



rim projects from the lid, whereby it is converted into a shallow vessel for holding water, the evaporation of which keeps the air sufficiently moist. The fire is lighted by first throwing in a few coals, then some sticks and paper, and, lastly, some cinders or coke, with a little coal immediately over the wood, taking care to make the fuel slope away from the smoke flue. The aperture at the top is then nearly closed, and the fire is lighted. The smoke first tends to rise towards the aperture, but the heat soon determines a downward current, which sets into the smoke aperture, and carrying with it the gaseous products of combustion into the flue, *f*, the fire soon begins to burn brightly. At night the aperture is closed, and the fire goes out. All the fuel is consumed, the downward draught producing complete combustion; there is no soot, and nothing of the fuel remains but a red ash. The management of this stove is quite easy; all that is required being to push in the slide, over the ash-pit before the fire is lighted, to let the fire burn brightly before much fuel is put on, and to keep the smoke vent, *x*, from being choked up, by overloading it with fuel.

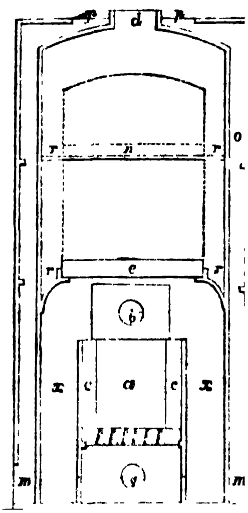
Mr. Beaumont says, that although this stove thoroughly warmed the air of the office, yet the clerks constantly complained of cold feet. To remedy this, a flue was formed under the paved floor, the paving-stones forming the roof of it. The

flue, which was a foot square, entered one side of the office, continued along that side, across the top, and down the other side, where it entered an upright flue in the party wall. The pavement thus heated after the Chinese fashion (page 55), made the office very comfortable. With a mere handful of fire, the warmth was so considerable, that the difficulty was to keep it low enough, without putting out the fire. An office and principal staircase were thus kept warm at an annual expense of 30*s*., or about 3*d*. a day for the cold season, whereas a similar degree of heat from another apparatus cost £18 a year. "Persons coming in from the open air have complained of our keeping large fires, and when they have been shown that the fire was a small one, burning without fierceness, and which might be contained in the crown of a hat, they have denied their belief to the fact; and insisted that the warmth which they felt must have been procured from some other source. It really does appear like magic, but the case proves the fact of one part only of the heat from the previous apparatus going to the place to be heated, and that eleven parts went up the chimney and was wasted at the house top."

The stove shewn in section, in Fig. 34, is an improvement on the Dutch stove, already noticed (page 97). The fire-chamber, *a*, eight inches on each side, is enclosed by four fire-tiles, *c c*, one inch thick, placed in a cast iron case, three eighths of an inch thick, with a ledge to support the grate. This ledge projects three and a half inches downwards into the ash-pit, and terminates in four short standards, or feet, placed on the sole of the stove. A space, *x*, of four and a half inches, is left between this iron casing, and the inner casing of the stove. Five inches above the upper edge of the tiles of the fire-box, a fire-tile, *e*, one and a half inch thick, and 15½ inches square, is fixed on brackets, so as to leave a space, *r*, about one and a quarter inch all round, between it and the inner surface of the casing for the hot vapour from the fuel to rise upwards. A plate of iron, or a tile, *n*, is fixed about eight inches above the tile, *e*, leaving also a space, *r*, about one and a quarter inch

between its edge and the casing. The roof of the stove, about eight inches above the plate, terminates in the smoke-pipe, *d*; the fire-door and its valve are shown at *b*, and the ash-pit door and air-valve at *s*, the upper edge of this valve being half an inch above the under edge of the iron casing of the smoke-chamber. The stove is enclosed in a plate-iron casing, so as to leave a space, *o*, of one and a half inch round it. This casing is open at the bottom, *m m*, and at the top, *p p*, and has two fillets projecting about half an inch from its surface; no valve of any kind is attached to this outward casing, and the air circulates freely through the space, *o*, that it encloses. All the parts are accurately fitted, and no air enters the stove, except through the valves at *s* and *b*. In the specimen described by Mr. Bernan, "the heating surface was 20½ square feet, and the depth of coke in the fire-chamber was generally about five inches; and this was found sufficient for a room containing nearly 5,600 cubic feet of space. When there is fire, the hot vapour from the fuel being prevented from rising in a stream upwards by the tile, *e*, spreads along its under surface, and ascends all round the edge of the tile, through the narrow space, *r*, which brings the smoke into contact with a large surface of the iron casing, and this contact is prolonged until it reaches the roof, by flowing through the narrow space between the upper tile and the casing; the whole surface of the stove thus kept in contact with the smoke, is equally heated, and the air which rises freely in the space, *o*, being brought rapidly in contact with this hot surface, is genially warmed and emitted at *p* into the room."

Fig. 34.



A combination of the stove and the grate, combining the heating effect of the stove with the cheerful appearance and ventilating properties of the open fire, is known under the name of the *stove-grate*, or *Chapelle*; the latter name being derived from its resemblance to the chapels or oratories of the great churches. Professor Robison describes it as the most perfect method of warming an apartment. Its construction is as follows:—In the great chimney-piece is set a smaller one, of a size no larger than is sufficient for holding the fuel. The sides and back are of cast iron, and are kept at a small distance from the sides and back of the main chimney-piece, and continued down to the hearth, so that the ash-pit is also separate. The pipe or chimney of the stove-grate is carried up behind the ornaments of the mantel-piece, until it rises above the mantel-piece of the main chimney-piece, and is fitted with a register, or damper plate, turning round a transverse axis. The best form of this register is that of an ordinary fire-place, with its axis or joint close at the front, so that when open or turned up, the burnt air and smoke, striking it obliquely, are directed with certainty into the vent without any risk of reverberating and coming out into the room. All the rest of the vent is shut up by iron plates or brick-work out of sight.

The fuel being in immediate contact with the back and sides of the grate, raises them to a great heat, and they heat the air contiguous to them. This heated air cannot get up the vent, because the passage above these spaces are shut up. It therefore comes out into the room; some of it goes into the real fire-place, and is carried up the vent, and the rest rises to the ceiling, and is diffused over the room. The heating effect of this stove-grate is remarkable. Less than a quarter of the fuel consumed in an ordinary fire-place is sufficient, and this, with the same cheerful blazing hearth, and the salutary renewal of the air. Indeed, it often requires attention to keep the room cool. The heat communicated to those parts of the apparatus, which are in contact with the fuel, is needlessly great, so that it has been found an improvement to line

this part with thick plates of cast iron, or with tiles of fire-clay. These being bad conductors, moderate the heat communicated to the air. If the heat be still found too great, it may be brought under perfect management, by opening passages in the vent for the spaces on each side, so that the air heated by the sides of the stove-grate may ascend directly into the flue, instead of escaping into the room. These passages may be closed by valves, or trap-doors, moved by rods concealed behind the ornaments of the fire-place.

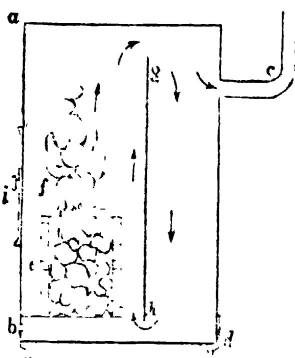
The stove-grate is under complete control as to temperature. A cheerful fire may be insured within five minutes, simply, by hanging a plate of iron in front so as to reach down as low as the grate; and when the fire is by its means blown up, the plate may be taken down and sent out of the room, or set up behind the grate out of sight. If, on the other hand, the room be found inconveniently warm, the temperature may be cooled down within a quarter of an hour, by opening the side passages to any extent for the escape of the hot air. In this arrangement the ash-pit is enclosed, because the light ashes not finding a ready passage up the chimney, are apt to escape into the room with the heated air.

Few contrivances for warming apartments have excited more attention and discussion of late years, than Dr. Arnott's stove. The principle of this invention consists, in allowing the fuel to burn very slowly, the admission of air for combustion being regulated by a peculiar contrivance. There are various forms and modifications of this stove, but the principle is the same in all. The stove consists of a square or cylindrical box of iron, lined with fire clay, with a grating near the bottom for the fuel, or the fuel may be contained in a small fire-box within the stove. Sometimes the fuel is burned within a hollow cylinder of fire-clay, and then the stove is not lined with that material. There is an ash-pit below for the ashes, and the products of combustion are carried off by a vent. The chief feature of this stove is, the contrivance by which the air is admitted to the fuel. When the stove-door or ash-pit door is open, the combustion is vivid; but when

these are perfectly tight, as they ought to be, then the air is admitted by a regulator.

The form first tried is shewn in Fig. 35, in which *a b c d*

Fig. 35.

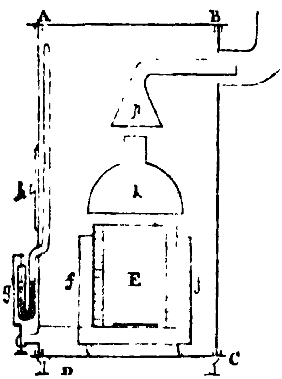


represent a box of sheet iron divided by the partition, *g h*, into two chambers, communicating freely at the top and bottom ; *e* is the fire-box formed of iron, lined with fire-brick, and resting on a close ash-pit with a door at *b*, near which is a valved opening, by which air enters to feed the fire when the door is shut ; *i* is the door of the stove by which fuel is introduced ; *c* is the chimney flue. When the ash-pit door and the stove-door are shut, the quantity of air admitted by the valved opening in the ash-pit is only just sufficient to support combustion, and only a small corresponding quantity of air can pass away by the chimney. The whole box then soon becomes filled with hot air, or smoke from the fire circulating in it, and rendering it every where of as uniform temperature, as if it were full of hot water. This circulation takes place, because the air in the front chamber around the fire-box, and which receives as a mixture the red-hot air issuing from the fire, is hotter, and, therefore, specifically lighter than the air in the posterior chamber which receives no direct heat, but is always losing heat from its sides and back ; and thus, as long as the fire is burning, there must be circulation. The whole mass of air is, in fact, seen to revolve, as marked by the arrows, with great rapidity. The quantity of new air rising from within the fuel, and the like quantity escaping by the flue, *c*, are very small compared by the revolving mass. The methods of regulating the supply of air will be noticed presently.

With this stove, Dr. Arnott, during the severe winter of 1836-7, was able to maintain in his library a uniform temperature of from 60° to 63°. The quantity of coal used

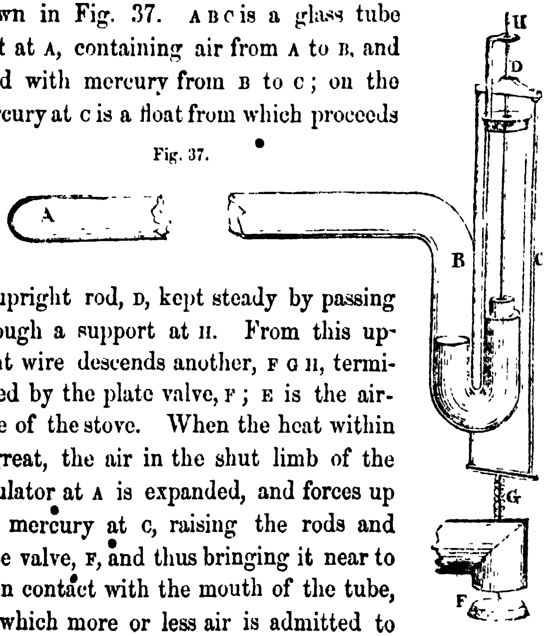
(Welsh stone coal) was, for several of the colder months, six pounds a day—less than a pennyworth—a smaller expense than that of the wood used in lighting an ordinary fire. The grate or fire-box, fully charged, held a supply for twenty-six hours.

Fig. 36.



Another common form of this stove is shewn in Fig. 36; A B C D, is the outer casing; E, the fire-box, over which is a dome, *k*, with a funnel, *p*, to carry off the products of combustion; *h*, is the stove door; and *g* the regulator by which air is admitted. Various forms of regulators are described, but perhaps the best is shewn in Fig. 37. A B C is a glass tube shut at A, containing air from A to B, and filled with mercury from B to C; on the mercury at C is a float from which proceeds an upright rod, D, kept steady by passing through a support at H. From this upright wire descends another, F G H, terminated by the plate valve, F; E is the air-tube of the stove. When the heat within is great, the air in the shut limb of the regulator at A is expanded, and forces up the mercury at C, raising the rods and plate valve, F, and thus bringing it near to or in contact with the mouth of the tube, by which more or less air is admitted to

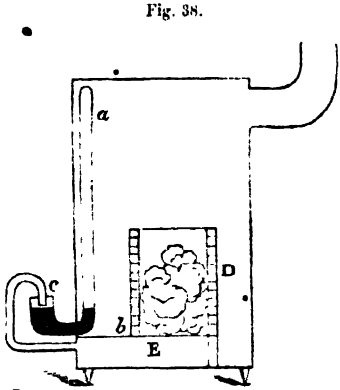
Fig. 37.



the stove, according to the heat within. If the combustion is proceeding too slowly, then the air in the tube A is not much expanded, consequently, air is allowed to enter the stove more freely.; but when owing to this the combustion becomes lively, and the temperature too high, then by the elevation of the plate valve, less air enters, and the temperature is moderated.

A still more simple form of regulator is shewn in Fig. 38, *a b c* is a bent tube shut at *a*, where it contains air, and open at *c*, where it is cup-shaped. The bent part at *b* is occupied by mercury; from *c* proceeds a bent tube to supply air to the stove. When the internal heat is great, the air in *a* is expanded and forces the mercury up in *c*, and thus, bringing it in contact with the mouth, prevents the free entrance of air to the stove.

Fig. 38.



This stove is liable to the objection already stated, viz., that the air of the room, though sufficiently heated, is nevertheless stagnant. A pound of coal requires about 150 cubic feet of air for combustion; but as a portion of the air escapes without being chemically acted on, 200 cubic feet may be allowed. Now if a room warmed by Arnott's stove, be fifteen feet long, twelve feet wide, and eleven feet high, its cubic contents are 1,980 feet; and if six pounds of coal per day be burnt, each pound requiring about 200 cubic feet, only 1,200 cubic feet will be used for the combustion. This quantity must pass through the stove, and be carried off by the vent, so that in the course of twenty-four hours, the atmosphere of the apartment is not once completely changed or renewed by the action of the fire. Hence it is that the apartment is so easily warmed, and hence also its unpleasant effect.

Another serious objection to this stove, arises from that

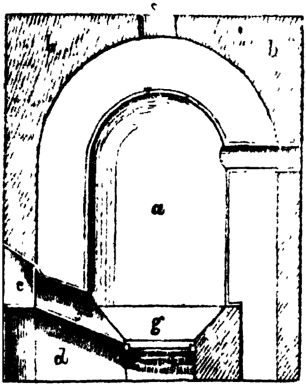
which is generally considered as its chief merit; namely, the slow combustion of the fuel, whereby carbonic oxide is generated, and from the small draught of the chimney, is liable to escape into the room. This gas, is poisonous, and its escape has been ascertained by Dr. Ure, by attaching to the ash-pit of one of these stoves a glass vessel containing a solution of subacetate of lead, which being speedily acted on by the carbonic oxide, was formed into the insoluble carbonate of lead. It is also stated, that carburetted hydrogen is sometimes formed in these stoves, which, by mingling with the air, has formed an explosive mixture, and thus led to calamitous fires.

Joyce's stove for burning charcoal is liable to all the objections arising from the use of this fuel in an apartment. The charcoal is prepared for this stove by reburning common charcoal in a close oven, and quenching it while hot with an alkaline solution; this deprives it of its usual pungent smell in burning, but renders it all the more dangerous, since the carbonic acid may slowly accumulate in an apartment, a bed-chamber, for example, and produce fatal consequences. The stove consists of a thin metal case, in the form of a small urn or vase. A small pipe, two or three inches long, rises through the bottom into the body of the stove, and terminates about the centre in a conical funnel closed at the top, and pierced full of holes. At the top of the stove is a valve, for the purpose of regulating the supply of air through the lower pipe, to maintain the combustion. A small portion of ignited charcoal is placed in the stove, and the remaining space filled up with charcoal not ignited; and as the supply of air is very limited, it will continue to give out heat for many hours. The whole of the charcoal is converted into carbonic acid, which escapes from the valve at the top in proportion to the quantity of air which enters at the bottom. This stove has nothing to recommend it; for the charcoal fuel is not only dangerous, but expensive. From its small size and great calorific power, this stove excited considerable attention at the

time of its introduction; and from the statements made respecting it, the public was led to expect that some new law of combustion had been discovered, or that the old law had been suspended in its favour, for it was gravely affirmed, that the whole of the products of combustion were absorbed or otherwise prevented from escaping from the stove, in consequence of the peculiar mode of preparing the fuel.

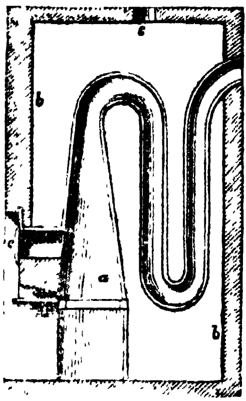
We come now to notice that variety of stove in which the *cockle* is introduced. This contrivance is an invention of Mr. Strutt, of Derby, and consists in making the fire-chamber of a cylindrical form, with a flat or dome-shaped head, and a pipe leading from the upper part, to carry off the smoke into the chimney. This iron fire-room, called the *cockle* from its shape, was then placed on a bed of masonry or brickwork, with a grating and ash-pit beneath, as shewn in Fig. 39. At a certain distance from the cockle, *a*, is a mass of brickwork, *b b*, concentric with the cockle and its dome top, in order to allow a current of air from the passages below, or from the external atmosphere, to come in immediate contact with the whole surface of the iron chamber and pipe. This air being thus heated and rarified, ascends towards the head of the stove, and passes through one or more apertures, *e*, into the room required to be warmed. The fuel is supplied at the door, *c*, and passes down a sloping dead plate to the fire-bars at *g*. The ash-pit and draught-hole for the fire are shewn at *d*.

Fig. 39.



In order to bring the air in contact with a greater extent of heated surface, another form is sometimes given to the cockle, by contracting its diameter, and bending the iron pipe into a serpentine form, as shewn in Fig. 40. The fire-chamber is

Fig. 40.

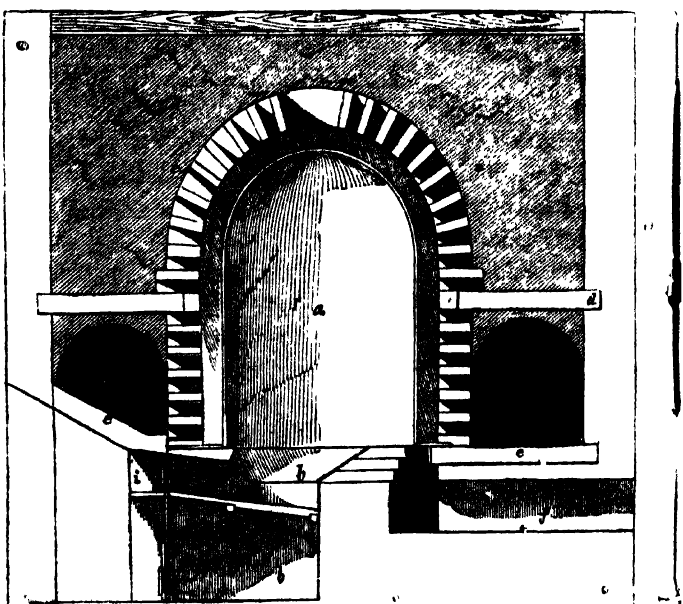


formed by placing the grating near the lower part of the conical pipe *a*, the opening to which for the admission of the fuel is at *c*; another narrow opening is made immediately in front of the fire-bars, to allow the ashes to be cleared from the bottom of the fire. The brickwork, *b*, enclosing the cockle, is in the form of a parallelogram, and the heated air escapes through *e*, and is conducted by pipes to the rooms required to be heated. The following is the working effect of a cockle of this kind, but with only one bend in the pipe, which entered the chimney lower down instead of proceeding upwards to *d*. The cockle itself was two and a quarter feet wide, six feet high, and the sides three quarters of an inch thick. The brick casing was at the distance of six inches from the metal, and the descending vent within was six inches in diameter. The stove here described was used for warming a lecture-room 35 feet long, 27 broad, and 20 high; also a large apartment 30 feet long, 27 broad, and 18 high; besides two smaller rooms and a staircase. The fire was kindled during winter at seven A.M., and kept burning till four P.M., when it was allowed to go out. The average quantity of coals consumed was rather less than half a hundred weight. The temperature of the air from the tubes varied from 120° to 180°, according to the state of the fire. The temperature of the different apartments was kept at about 60°. When first erected, the supply of air for the hot chamber was brought from without; but afterwards, the air for the fuel and for the hot chamber were both taken from the apartment containing the stove, which was generally at 70°.

Mr. Strutt, of Belper, in Derbyshire, appears to have been the first person who introduced the cockle-stoves, and hence,

they are often named in honour of him *Belper stoves.* In 1792, he warmed his large cotton factories by their means; but the cockle-stove, erected by Mr. Charles Sylvester for warming the Derby Infirmary, was long regarded as a model of its kind for a large building. In a stove of this kind, it is necessary that the area be such as to allow of the subterranean passage being carried out, so as to communicate with the external atmosphere at some convenient distance from the building, in order to admit a current of cool air for ventilation during summer, as well as for the supply of the stove for warming the air of the apartments in winter. The stove should also be erected as near the area of the building as convenient, and be placed from six to twelve feet below the floor, in order to preserve uniformity as much as possible in the distribution of the warm air. The cockle, *a* (Fig. 41), is cubical in form, with a dome or groined arch top; it is about

Fig. 41



three feet in diameter, and four feet high, and is made of iron plates rivetted together. The smoke passes off by a narrow passage at the base of the cockle through the flue *f*. The brickwork surrounding the cockle is built with alternate openings between the bricks, as in Fig. 41, at about eight inches distant from the sides of the cockle. Through these apertures are inserted pipes of sheet iron, or common porcelain-ware, so as to extend within an inch of the cockle, by which means the air to be heated may be thrown near, or in immediate contact, with the surface of the cockle, if desirable. The horizontal partition, *d d*, cuts off the communication between the lower and the upper portion of the air-chamber, the arched openings in the lower half, *c c*, being the openings of the main air-flue leading from the exterior atmosphere. The fire-room and ash-pit are shewn at *b b*, and the fuel is introduced by the opening at *i*.

It will be seen, from this arrangement, that the air passing from the lower flues, *c c*, through the apertures beneath the horizontal partition, and coming in immediate contact with the surface of the cockle, must find its way into the upper air-chamber, *e e*, through the numerous pipes or openings of the upper division, by which circuit its velocity will be sufficiently retarded to obtain the necessary elevation of temperature from the heated cockle. But that the air may not be burnt, it is necessary to regulate the size of the fire-chamber, so as not to heat the cockle, on an average, more than 300°. The Derby stove allows the passage of nearly five cubic feet of air per second, which is heated to about 130° at the instant it escapes from the upper air-chamber into the pipes leading to different parts of the building. These pipes are furnished with dampers to regulate the admission of warm air at pleasure.

If care be taken to prevent the burning of the air, this method of heating a large building appears to be wholesome and economical. It would scarcely answer on a small scale, on account of the expense of erection; nor could it be easily applied to a large building, unless constructed in the first

instance, or during the erection of the edifice. The air passages being placed several feet below the surface of the ground, affords a convenient mode of admitting a portion of cold air to the interior of the building during summer, by means of a revolving mouth-piece, or turn-cap, placed at the opening of the air-passage, so as to receive the current of wind at the outer extremity of the passage, and thus convey it to the interior of the building.

The various objections which have been urged, from time to time, against this method of warming buildings, by bringing the air into contact with a surface of iron heated by fire, have led to other methods of heating the metallic surface. Thus Mr. John Sylvester, in his evidence before the House of Commons' Committee, in 1835, proposed this method of warming the New Houses of Parliament. An apparatus was to be erected beneath the house, or on the basement, constructed of cast iron, and exposing a very large surface for the contact of the fresh air; the arrangement of the surface being such as to divide the supply of fresh air into a large number of very small streams. The under part of the metal surfaces being heated by enclosing water, or steam, the air so divided would flow in contact with such warming surfaces, and thus become heated to the temperature required. When thus heated, it would be allowed to flow under the whole area of the house, the floor of which, being perforated with a multitude of holes, would thus admit it into the body of the house. (See Fig. 87)

This brings us to the next step in the art of warming buildings; namely, by *steam*, for the details of which we refer to the next Chapter.

CHAPTER III.

ON THE WARMING OF BUILDINGS BY MEANS OF STEAM AND HOT WATER.

THE method of warming buildings by steam, depends on the rapid condensation of steam into water when admitted into any vessel which is not so hot as itself. At the moment of condensation, the latent heat of the steam is given out to the vessel containing it, and this diffuses the heat into the surrounding space.

The first practical application of this principle was made by James Watt, in the winter of 1784-5, who fitted up an apparatus for warming his study. The room was 18 feet long, 14 feet wide, and 8½ feet high. The apparatus consisted of a box, or heater, made of two side plates of tinned iron, about 3½ feet long by 2½ feet wide, separated about an inch by stays, and jointed round the edges by tin plate. This heater was placed on its edge, near the floor of the room. It was furnished with a cock to let out the air, and was supplied with steam by a pipe from a boiler, entering at its lower edge, and by this pipe, the condensed water also returned to the boiler. The heating effect of this apparatus was not so great as was expected, in consequence, perhaps, of the bright metallic surfaces of the box not being favourable to radiation.

In 1791, Mr. Hoyle, of Halifax, took out a patent for heating by steam pipes, and his method seems to have been the foundation for subsequent attempts. The steam was at once conveyed from the boiler, by a pipe, to the highest elevation of the building required to be heated, and, from that point, by a gentle declivity, the condensed water flowed into the supply cistern of the boiler. The effect of the pipes (which were of copper) was too small, and as the apparatus was constantly getting out of order, it was pronounced a failure.

In 1793, Mr. Green took out a patent for a different method,

which consisted in enclosing a hollow vessel, or worm pipe, in a boiler containing hot water or steam. The air, on its way to the room to be warmed, was made to pass through this worm, and was thus heated to an agreeable temperature. By another method, pipes from a steam boiler were enclosed in other pipes, and, in the interval between them, the air was heated on its passage to the room. This apparatus was erected in a mansion on Wimbledon Common. The encased pipe was fixed along the ceiling of the basement floor, with an inclination of two inches in 68 feet. The inner steam pipe was three inches in diameter, the outer pipe nine inches, and both of copper. The lower end of the casing pipe was left open for the cold air to enter ; the other end was joined to a pipe four inches in diameter, with three horizontal elbows, that rose about twelve inches, where it opened into the first suite of rooms that were to be heated. It was supposed that the air would enter at one end in great quantity, and flow out through the small pipe at the other end into the rooms ; the effect, however, was so feeble, that no useful heating was produced.

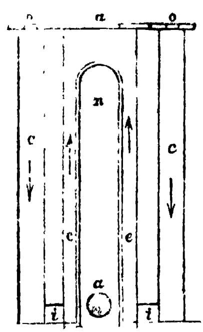
About this time, steam was introduced into hot-houses, not by circulating in pipes, but by being discharged into the body of the hot-house, the effect of which was to raise its temperature and moisten the air to such a degree, that the plants grew rapidly and luxuriantly. It is also said to have had the effect of destroying insects.

In the winter of 1795-6, Mr. Boulton erected a steam heating apparatus in the library of his friend, Dr. Withering, "which, in point of heating, answered perfectly ; but the pipes being made of copper, and soft soldered in some places, the smell of the solder was rather unpleasant to the Doctor, who was then in an infirm state of health with diseased lungs. The apparatus was, in consequence, removed to Soho, where Mr. Boulton proposed erecting it in his own house, in which he was making alterations about this time, and had it in view to heat every room in the house by steam. A boiler was put

up for that purpose in one of the cellars, but some circumstance occurred to prevent his continuing the plan. The subject, however, underwent frequent discussions, and the different modes of effecting it were amply considered by Messrs. Boulton and Watt, as was known to many of their friends, no secret having been made, either of calculations of surface, or of the modes of applying them."*

About the end of the year 1799, Mr. Lee, of Manchester, under the direction of Boulton and Watt, erected a heating apparatus of cast iron pipes, which served also as supports to the floor. This answered perfectly, and was, in point of materials and construction, the earliest of its kind. Mr. Lee afterwards had his house heated by steam, and the staircase, hall, and passages, were warmed by the apparatus shewn in Fig. 42. It was placed in the underground story, and consisted of a vertical cast iron cylinder, *a*, surrounded by a casing of brick-work, leaving a space, *e e*, of two and a half inches all round, and having openings, *i*, below, to admit the air. This casing was surrounded, at the distance of three or four inches, by another wall, forming a sort of well, *c*. The colder and heavier air falling to the bottom of this well, entered by the holes, *i*, into the space, *e*, where it came in contact with the cylinder, *a*, and, being heated, ascended. The entrance of the steam into the cylinder, was regulated by a valve, the air being allowed to escape by a stop-cock, while the steam was entering; the condensed water escaping by a pipe not shewn in the figure. The transmission of the heated air was regulated by a valve at *a*, on the top of the brick-work. This apparatus was so effective, and heated the staircase to such a degree, that after it had been in operation a short time, it was necessary

Fig. 42.



* *Buchanan on the Economy of Fuel, &c.*, 1810. Second Edition, 1815.

to suspend its action by closing the valve at *a*, or by closing the valve which admitted steam into the cylinder.

The method of heating buildings by steam has scarcely advanced since the time when Messrs. Boulton and Watt erected their apparatus for the purpose, and Mr. Buchanan wrote a practical treatise on the subject. The hot-water apparatus has, for the most part, superseded the steam apparatus, so that our details need not be very full.

In establishments where a steam-engine is in daily use, the steam pipes may be supplied from the engine boiler, its dimensions being enlarged at the rate of one cubic foot for every 2,000 cubic feet of space, to be heated to the temperature of 70° or 80°. A boiler adapted to an engine of one-horse power, is sufficient for heating 50,000 cubic feet of space. Hence an apparatus specially erected for the purpose, need not be of very large size, nor is the quantity of fuel consumed great. If the fire under a small boiler be carefully managed, 14lbs. of Newcastle coal will convert one cubic foot of water at 50°, into 1,800 cubic feet of steam at 216°; and only 12lbs. of coal are required to convert the same quantity of water into steam at 212°. The shape of the boiler, and the method of setting it, must also be considered, and the furnace must be arranged so as to admit no more air than is required to support the combustion. The hot air must also be kept in contact with the sides of the boiler, until as much of the heat as possible be abstracted from it. In such an arrangement, according to Dr. Arnott, nearly half of all the heat produced in the combustion is applied to use.

In estimating the extent of surface of steam pipe required to raise the rooms to the proper temperature, it is necessary to consider how the heat is expended. This is done in three ways:—1, Through the thin glass of the windows. 2, More slowly through the walls, floors, and ceiling; and 3, In combination with the air which escapes at the joinings of the windows and doors, or through openings expressly made for the purpose of ventilation. The amount of heat lost in this way

has been variously estimated by different writers, but Dr. Arnott states it thus:—That in a winter day, with the external temperature at 10° below freezing, to maintain in an ordinary apartment the agreeable and healthful temperature of 60°, there must be of surface of steam pipe, or other steam vessel heated to 200° (which is the average surface-temperature of vessels filled with steam of 212°), about one foot square for every six feet of single glass window of usual thickness; as much for every 120 feet of wall, roof, and ceiling of ordinary material and thickness; and as much for every six cubic feet of hot air escaping per minute as ventilation, and replaced by cold air. A window, with the usual accuracy of fitting, allows about eight feet of air to pass by it in a minute, and there should be for ventilation, at least three feet of air per minute for each person in the room. According to this view, the quantity of steam pipe, or vessel, needed, under the temperature supposed, for a room 16 feet square by 12 feet high, with two windows, each 7 feet by 3, and with ventilation, by them or otherwise, at the rate of sixteen cubic feet per minute, would be—

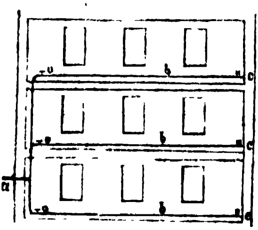
	Feet.
For 42 square feet of glass (requiring 1 foot for 6)..	7
„ 1,238 feet of wall floor and ceiling (requiring 1 foot for 120)........................	$10\frac{1}{3}$
„ 16 feet per minute for ventilation (requiring 1 foot for 6)...........................	$2\frac{2}{3}$
Total of heating surface required........	20

Which is 20 feet of pipe, 4 inches in diameter, or any other vessel having the same extent of surface,—as a box two feet high, with square top and bottom of about eighteen inches. It may be noticed, that nearly the same quantity of heated surface would suffice for a larger room, provided the quantity of window glass, and of the ventilation, were not greater; for the extent of wall, owing to its slow conducting quality, produces comparatively little effect.

The same excellent authority also supplies the following illustrations :—A heated surface, as of iron, glass, &c., at temperatures likely to be met with in rooms, if exposed to colder air, gives out heat with rapidity, nearly proportioned to the excess of its temperature above that of the air around it, less than half the heat being given out by radiation, and more than half by contact of the air. Thus, if the external surface of an iron pipe, heated by steam, be 200°, while the air of the room to be warmed by it, is at 60°, shewing an excess of temperature in the pipe of 140°, such pipe will give out nearly seven times as much heat in a minute as when its temperature falls to 80°, because the excess is reduced to 20°, or $\frac{1}{7}$ of what it was. Supposing window glass to cool at the same rate as iron plate, one foot of the steam pipe would give out as much heat as would be dissipated from the room into the external air by about five feet of window, the outer surface of which were 30° warmer than that air. But as glass both conducts and radiates heat about $\frac{1}{7}$ slower than iron, the external surface of the glass of a window of a room, heated to 60°, would, in an atmosphere of 22°, be under 50°, leaving an excess of less than 30° ; and about six feet of glass would be required to dissipate the heat given off by one foot of the steam pipe. In double windows, whether of two sashes, or of double panes, only half an inch apart in the same sash, the loss of heat is only about one-fourth of what it is through a single window. It is also known that one foot of black or brown iron surface, the iron being of moderate thickness, with 140° excess of temperature, cools in one second of time 156 cubic inches of water, one degree. From this standard fact, and the law above given, a rough calculation may be made for any other combination of time, surface, excess, and quantity. And it is to be recollected, that the quantity of heat which changes, in any degree, the temperature of a cubic foot of water, produces the same change on 2,850 cubic feet of atmospheric air.

The arrangement of the steam pipes has next to be considered. A common method is shewn in Fig. 43, in which

Fig. 43.



a is the pipe from the boiler, rising at once to the upper story. From this pipe proceed horizontal branches, *b b*, to each floor. Each branch is furnished with a stop-cock at *o*, by which means the steam can be turned on or off at pleasure, in any one of the three stories. The water arising from the condensation of the steam in each pipe, flows back into the boiler along the ascending pipe. But if it be not convenient to place the boiler below the level of the lowest floor, the condensed steam is received into a reservoir, from which it is pumped into the feeding cistern. At the extremity of each horizontal branch, c, is a stop-cock, which is opened, when the steam is filling, to allow the air to blow off.

Another arrangement of the heating pipes is shewn in

Fig. 44.

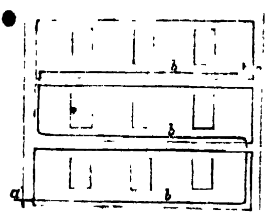
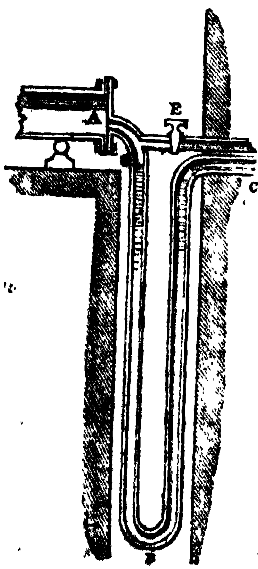


Fig. 44. Steam from the boiler enters by the connecting pipe, *a*, into the heating pipe, *b*, placed near the floor, and this is carried, with a gentle slope, to the opposite side of the room, whence it rises into the next story, and returns along its floor to the opposite side, where it rises to the third floor, and proceeds as before. Here, also, the condensed water flows back in a direction contrary to the current of the steam, and is removed by a siphon at *a*. The air-vent is fixed at the highest point of the arrangement, *c*.

It is necessary to prevent the condensed water from accumulating in the pipes, otherwise it would be impossible to maintain them at a uniform temperature. Moreover, this water condenses the steam so rapidly, that a vacuum is formed within the boiler and pipes; and should they not be firm enough to resist the external pressure of the atmosphere, the boiler may be crushed in, and the whole system deranged. By a special arrangement, the condensed water is collected at

certain parts of the system, where it continues to give out heat after the steam has ceased to flow into the pipes. In such cases, stop-cocks may be employed, so arranged as to allow the water to be afterwards withdrawn from the pipes; the same cocks also serve for letting the air out of the pipes when the steam is first admitted; but when the water is returned into the boiler, the advantage of this supply of heat cannot be reserved; and in these cases, a self-acting apparatus is used for taking off the water of condensation. Such a siphon is represented in Fig. 45. The pipes are so fixed, that A is the lowest point of a branch pipe, so that any quantity of water that may be formed in it, will flow into the siphon, A B C, at A, and escape at C, where it may be received into any vessel, for as the water is pure distilled water, it may be useful for a variety of purposes. The water in the legs of the siphon acts as a trap to the steam in the pipe, A; hence, the length of the leg, A B, should not be less than is equivalent to the force of the steam in the pipes. When, for example, the steam is worked at the rate of ten pounds per square inch, the column of water should not be less than ten feet, and even with this pressure, there will be considerable oscillations, unless a valve be placed at some intermediate point between A and B. When the legs are both filled with water, and at rest, this valve should be open, so as to close whenever the water has a tendency to return into the pipe. The siphon should be large enough to carry off all the water of condensation, but not too large, or there would be a loss of heat in the leg, A B, from its being filled with steam; and, in all cases, the siphon should be protected from frost. In connection with the siphon,

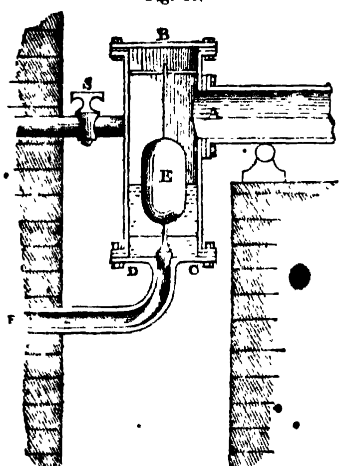
Fig. 45.



it is usual to place a cock for letting the air out of the pipe, instead of the stop-cock above referred to. Such a cock is shewn at E, and it is made to range with the lower part of the pipe, because the air being heavier than steam, will occupy only the lower portion of it.

In cases were sufficient depth cannot be afforded for a siphon, a steam trap, or valve, made to open by a float ball, is employed.

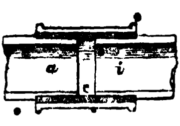
Fig. 46.



Tredgold's arrangement is as follows:—B C (Fig. 46), is a square box attached to the end, A, of the steam-pipe; D is a hollow copper cylinder, fixed to a conical valve, E; when steam is condensed, the square box will fill with water, which will float the hollow cylinder, and the water will escape, and run by the pipe, F, into the drain; whenever the quantity of water in the box is greater than is required just to float the cylinder, and when there is less than will float it, the valve will be closed. In this case also, a stop cock, S, will be necessary to let out the air while the pipes are being filled with steam.

The various methods of connecting the cast iron pipes are by the flange joint, and the spigot and faucet, or socket joint. Mr. Buchanan gives minute directions for these, but he seems inclined to recommend the thimble joint. Care must, of course, be taken in joining the pipes, to allow room for expansion. This is sometimes done in the thimble joint (Fig. 47), in which the adjoining ends of the pipes, *a i*, are turned true on the outside, and have a thimble, or short cylinder of wrought iron, to enclose them, leaving only a small space

Fig. 47.



for the current. A piece of tin, *c*, or inner thimble, is interposed, and made to fit well to the turned parts of the pipes, which, under the influence of heat or cold, work forwards or backwards, like a piston in a cylinder. In a range of pipes 120 feet in length, there was a motion from expansion of three quarters of an inch; but the usual allowance for the expansion of cast iron pipes, is one eighth of an inch in 10 feet, or $\frac{1}{960}$ of their length. Cast iron, heated from 32° to 212°, expands $\frac{1}{900}$ of its length, which is nearly one and three eighths of an inch in 100 feet. A similar expansion joint applied to the spigot and faucet connection (Fig. 48), answered very well. Lead cannot be substituted for tin or iron cement in joints, for, by frequent heating, it becomes permanently expanded, while the iron pipes always contracting in cooling, and the lead not participating in the contraction, the joints soon get loose. Count Rumford introduced an expansion drum, *x* (Fig. 49), of thin copper, between the extremities of two pipes, *a i*, which, in elongating, pressed the sides of the drum inwards, and in cooling drew them outwards. The pipes should not be connected with any part of the building, but be quite independent thereof; all the horizontal branches should be supported on rollers, and nothing done to interfere with the expansion of the different parts.

Fig. 48.

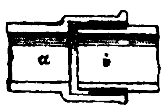
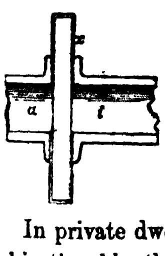


Fig. 49.



In private dwellings, where the appearance of the pipes is objectionable, they may be concealed behind perforated mouldings, or skirtings, or cornices; or the steam may be brought into ornamental vases dispersed about the room, each furnished with a small stop-cock, to allow the air to escape while the steam is entering.

The method of heating buildings by steam has been long superseded by hot water apparatus of various kinds, which, however, may be resolved into two distinct forms or modifications, dependant on the temperature of the water. In the

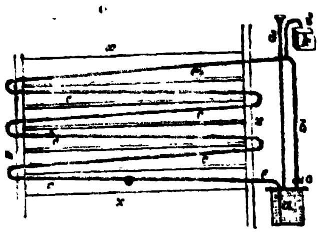
first form of apparatus, the water is at or below the ordinary temperature of boiling. In this arrangement the pipes do not rise to any considerable height above the level of the boiler, so that the apparatus need not be of extraordinary strength. One pipe rises from the top of the boiler, and traverses the places to be warmed, and returns to terminate near the bottom of the boiler. Along this tube the heated water circulates, giving out its heat as it proceeds. The boiler may be open or closed. If open, the tube, when once filled with water, acts as a siphon, having an ascending current of hot water in the shorter leg, and a descending current of cooled water in the longer leg. If the boiler be closed, the siphon action disappears, and the boiler with its tubes become as one vessel. In the *second* form of apparatus, the water is heated to 350° and upwards, and is, therefore, constantly seeking to burst out as steam, with a force of 70lbs. and upwards on the square inch, and can only be confined by very strong or high pressure apparatus. The pipe is of iron, about an inch in diameter, made very thick. The length extends to 1,000 feet and upwards, and where much surface is required for giving out heat, the pipe is coiled up like a screw. A similar coil is also surrounded by the burning fuel, and serves the place of a oiler.

The heating of rooms by the circulation of hot water in pipes, seems to have occupied the attention of a few speculative individuals, long before the attempt was actually made. The first successful trial is assigned to Sir Martin Triewald, a Swede, who resided for many years at Newcastle-on-Tyne, and about the year 1716, described a method for warming a greenhouse by hot water. The water was boiled outside the building, and then conducted by a pipe into a chamber under the plants.

But the first successful attempt, on a large scale, was made in France, in 1777, by M. Bonnemain, in an apparatus for hatching chickens, for the purpose of supplying the market of Paris. A section of this heating apparatus is shewn in Fig. 50, in which *a* is the boiler, *d* a feed-pipe, *o* a stop-cock, for regulating the quantity of ascending hot water, *b* the

pipe by which the hot water ascends from the boiler into the heating pipes, *c c*, which traverse the hatching chamber. These heating pipes have a gradual slope towards the boiler, to which the water returns by the pipe, *e*, carried nearly to the bottom. In this way the water, cooled by being circulated through a long series of pipes, is being constantly returned to the lowest part of the boiler, where it receives a fresh amount of heat, and being thus rendered lighter, rises up the pipe, *b*, and descends the inclined planes of the pipes, losing a portion of its heat on the way, and at the same time increasing in density; the velocity of the current depending on the difference between the temperature of the water in the boiler, and that in the descending pipe. At the highest point of the apparatus is a pipe, *i*, furnished with a stop-cock for the escape of the air which the cold water holds in solution on entering the boiler. The water that rises along with it is received into the vessel *k*.

Fig. 50.



The arrangements of this apparatus are excellent; they have been taken as a model in many subsequent methods, although the merits of the inventor have not always been acknowledged. The plan was introduced into this country in 1816, by the Marquis de Chabannes, who was long regarded as the inventor. About the year 1822, Mr. Bacon and Mr. Atkinson introduced modifications of the apparatus, but the latter gentleman succeeded in reducing it to its most simple and practical form.

Whatever be the arrangement adopted for warming buildings by this method, two considerations must be specially attended to, namely, sufficient strength to bear the hydrostatic pressure, and freedom of motion for currents of water, of varying temperatures, and consequently of varying densities. As fluids transmit their pressure equally in every direction, a

column of water rising from a strong vessel to a certain height, may be made to burst the vessel with enormous force. Thus a tube whose sectional area is one inch, rising to the height of 34½ feet from the bottom of a vessel of water, will, if the tube be also full of water, exert a bursting pressure on every square inch of the inner surface of such vessel of one atmosphere, or 15lbs. If the sectional area of the tube be increased, the pressure remains the same, because it is distributed over a larger surface of the vessel. If a boiler be 3 feet long, 2 feet wide, and 2 feet deep, with a pipe 28 feet high from the top of the boiler, when the apparatus is filled with water, there will be a pressure on the boiler of 66,816lbs. or very nearly 30 tons. This will shew the necessity for great strength in the boiler, especially when it is considered that the effect of heat upon it is to diminish the cohesive force of its particles. But even supposing the apparatus were to burst, no danger would arise, because water, unlike steam, has but a very limited range of elasticity. The boiler just described would contain about 75 gallons of water, which under a pressure of one atmosphere on the square inch would be compressed about one cubic inch; and if the apparatus were to burst, the expansion would only be one cubic inch, and the only effect of bursting, would be a cracking in some part of the boiler, occasioning a leakage of the water.

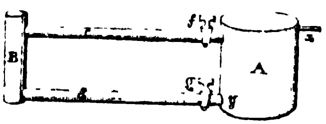
The circulation of the water is brought about by the principle of convection already explained in the case of air (page 31). When heat is applied to a vessel containing water, the principle of conduction altogether fails, for water is so imperfect a conductor of heat, that if the fire be applied at the top, the water may be made to boil there without greatly affecting the temperature below. But when the fire is applied below the particles in contact with the bottom of the boiler, being first affected by the heat, expand, and thus becoming specifically lighter than the surrounding particles, ascend, and other particles take their place, which in like manner becoming heated, ascend also; and the process goes on in this way until the

whole contents of the boiler have received an accession of temperature. If the process be continued long enough, the water will boil and pass off in steam; if the boiler be closed in on all sides, so as to prevent the escape of steam, it will burst with a fearful explosion. If a tube full of water rise from the top of the boiler in a vertical line to any required height, and then by a series of gentle curves descend, and enter near the bottom of the boiler, the process of heating is still the same. The particles of water first heated, will rise, and, in doing so, distribute their heat to other particles, which will also rise; these in their turn will lose a portion of their heat to other particles, which rise in their turn; until at length an equilibrium is established. But as the source of heat is permanent, other particles are rapidly brought under its action, and, being heated, ascend. By continuing the process a short time, the particles in the vertical tube become heated, and, by their expansion, exert a pressure on the water contained in the lateral branches; this, together with the increasing levity of the water in the boiler, establishes a current, and the water from the branches begins to set in, in the direction of the boiler; the water in the lowest branch, where it enters the boiler, supplying colder and heavier particles every moment to take the place of the warmer and lighter particles which are being urged upwards along the vertical pipe.

Now to ascertain the force with which the water returns to the boiler, we must know the specific gravities of the two columns of water, the ascending and the descending, and the difference between them will be the effective pressure, or motive power. This can be done by ascertaining the temperature of the water in the boiler, and in the descending pipe. When the difference amounts to only a few degrees, the difference in weight is very small, but quite sufficient in a well arranged apparatus to maintain a constant circulation. For example, suppose an apparatus to be at work, in which the temperature in the descending pipe is 170°, and the temperature of the water in the boiler, the height of which is 12 inches, is 178°.

The difference in weight is 8.16 grains on each square inch of the section of the return pipe. If the boiler, A (Fig. 51), be two feet high, and the distance from the top of the upper pipe, *c*, to the centre of the lower pipe, *d*, be 18 inches, and the pipe four inches in diameter, the difference of pressure on the return pipe will be 153 grains, or about one-third of an ounce weight, and this will be the amount of motive power of the apparatus, whatever be the length of pipe attached to it.

Fig. 51.



If such an apparatus have 100 yards of pipe, four inches in diameter, and the boiler contain 30 gallons, there will be 190 gallons or 1,900lbs. weight of water kept in continual motion by a force equal to only one-third of an ounce.*

The amount of motive power increases with the size of the pipe. The power being four times as great in a pipe of four inches in diameter as in one of two inches, as the former contains four times as much water as the latter; but as the resistance increases equally with the power, the actual working effect is the same in pipes of all sizes. The motive power is increased by allowing the water to cool before it returns to the boiler, or by increasing the height of the ascending and descending columns of water. By doubling the difference of temperature between the flow-pipe and the return-pipe, the same increase of power is obtained as by doubling the vertical height; and by tripling the difference in temperature, the same effect is produced as by tripling the vertical height. The difference in temperature may also be increased by increasing the quantity of pipe, or by diminishing its diameter, so as to expose a

* Mr. Hood in his *Treatise on Warming Buildings by Hot Water, &c.*, gives a table shewing the difference in weight of two columns of water, each one foot high, at various temperatures. The writer takes this opportunity of expressing his obligations to this valuable work, to which he refers the reader who desires to master the subject on which it treats.

larger amount of surface, in proportion to the quantity of water contained in it, so as to allow it to part with more heat within a given time. But the method which must be principally depended on, when additional power is required to overcome any unusual obstruction, is to increase the height of the ascending column.

Another method of estimating the velocity of motion of the water of a hot-water apparatus, is to regard the two portions of the system, as the lighter and heavier fluids in the two limbs of a barometrical aëriometer. This instrument is an inverted siphon, Fig. 52, and its use is to ascertain, in a rough way, the specific gravities of immiscible fluids. If mercury be poured into one limb A, and water into the other, B, and the stop-cock at C be turned, so as to establish a communication between them, it will be found that an inch of mercury, F D, in one limb will balance thirteen-and-a-half inches of water, I E, in the other limb; thus shewing that the densities, or specific gravities, of the two fluids, are as thirteen-and-a-half to one. If oil be used instead of mercury, it will require ten inches of oil to balance nine inches of water. Or if equal bulks of oil and water be poured into the limbs of the siphon, and the stop-cock be then turned, the oil will be forced upwards with a velocity equal to that which a solid body would acquire in falling by its own gravity, through a space equal to the additional height which the lighter body would occupy in the siphon. Now as the relative weights of water and oil are as nine to ten, the oil in one limb will be forced upwards by the water with a velocity equal to that which a falling body (in this case, the water) would acquire in falling through one inch of space, and this velocity is equal to 138 feet per minute.

Fig. 52.

In estimating the velocity of motion of the water in a hot-water apparatus, the same rule will apply. "If the average temperature be 170°, the difference between the temperature

of the ascending and descending columns 8°, and the height ten feet; when similar weights of water are placed in each column, the hottest will stand .331 of an inch higher than the other; and this will give a velocity equal to 79.2 feet per minute. If the height be five feet, the difference of temperature remaining as before, the velocity will be only 55.2 feet per minute; but if the difference of temperature, in this last example, had been double the amount stated;—that is, had the difference of temperature been 16°, and the vertical height of the pipe five feet,—then the velocity of motion would have been 79.2 feet per minute, the same as in the first example, where the vertical height was ten feet, and the difference of temperature 8°."

But, in all these calculations, a considerable deduction must be made for the effects of friction. In the centre of the ascending pipe, the heated particles meet with the smallest amount of obstruction, and there the motion is quickest; but at and near the circumference of the pipe, the retarding effects of friction are most apparent. In the descending pipe the friction is less, for the water descends more as a whole, and is, moreover, assisted by the gravity of the mass. In an apparatus, where the length of pipe is not great, where the pipes are of large diameter, and the bends and angles few, a large deduction from the theoretical amount must still be made, to represent, with anything like accuracy, the true velocity; and Mr. Hood states, that in more complex apparatus, the velocity of circulation is so much reduced by friction, that it will sometimes require from 50 to 90 per cent., and upwards, to be deducted from the calculated velocity, in order to obtain the true rate of circulation.

The amount of friction not only varies according to the arrangement of the apparatus, but also according to the size of the pipes. It is much greater in small pipes than in large ones, on account of the relatively larger amount of surface in the former; besides this, small pipes cool quicker than large ones, and this increases the velocity of the circulation,

and with it, the friction is also increased. When the velocity with which the water flows, is the same in pipes of different sizes, the relative amount of friction is as follows :—

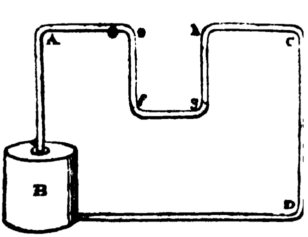
Diameter of the pipes,	½ inch,	1 in.	2 in.	3 in.	4 in.
The amount of friction,	8,	4,	3,	1.3,	1.

So that, if the friction in a pipe of 4 inches diameter be represented by 1, the friction of a pipe 2 inches in diameter is twice as much, and a 1-inch pipe four times as much. By increasing the velocity, the friction increases nearly as the square of the velocity ; but as the water in a hot-water apparatus circulates with various degrees of speed in its different parts, it is not easy to calculate the amount of friction from this cause.

It will be seen, then, that when all the deductions are made, the circulation of the water is produced by a very feeble power, so that, as may be supposed, a very slight cause is sufficient to neutralise it. Mr. Hood has known so trifling a circumstance as a thin shaving accidentally getting into a pipe, effectually to prevent the circulation in an apparatus otherwise perfect in all its parts.

But the great point to be attended to, is so to dispose the pipes, that the water, in its descent, may not be obstructed by differences of level, or angles in the pipes, where air may accumulate ; for this, by dividing the stream, effectually prevents the circulation. For example, in an apparatus constructed in the form represented in Fig. 53, the motion through the boiler and pipe, A B, takes place by convection, and through the descending pipe, C D, by the force of gravity, as already described. But, it will be seen, that when the motion commences in the return pipe, D B, in consequence of the greater pressure of C D than of A B, the water in A will be

Fig. 53.



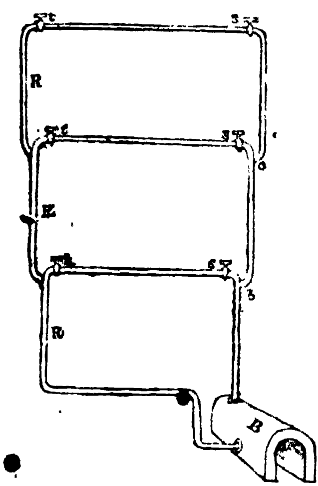
forced towards *e*, while the water in *e f g h* flows towards C. But when a very small quantity of hot water has passed from the pipe and boiler, A B, into the pipe *e f*, the column of water, *g h*, will be heavier than the column *e f*, and the current will, therefore, tend to move along the upper pipe towards the boiler, instead of from it. This force, whatever its amount, must oppose that in the lower or return pipe, in consequence of the pressure of C D being greater than A B; and unless the force of motion in the descending pipe, C D, be sufficient to overcome this tendency to a retrograde motion, and leave a residual force sufficient to produce direct motion, no circulation of the water can take place.

With respect to the accumulation of air in the pipes, every part of the apparatus, where an alteration of level occurs, must be furnished with a vent for the air. Thus, in Fig. 53, if the air accumulate in the pipe between A and *e*, it is evident that a vent at C, although it would take off the air from *g h*, and from C D, could not receive any portion of that which is confined between A *e*, or between *e f*, because, in that case, it must descend through the pipe, *e f*, before it could escape, and as air is so very much lighter than water, it cannot possibly descend so as to pass an obstruction lower than the place where it is confined. The same remark applies to all cases, however large or small the descent may be, and the accidental misplacing of a pipe in the fixing, by which one end may be made a little higher than the other, will as effectually prevent the escape of air through a vent placed at the lower end, as though the deviation from the level were as many feet as it may, perhaps, be inches.

When it is required to heat a number of separate stories by the same boiler, one of two methods may be adopted. The vertical pipe from the boiler may be carried up to the highest story, and the return pipe meander through each story, until it finally terminates in the boiler. But it is obvious, that in such case, the top story will get the larger share of the heat, and the lower stories will be gradually less heated, on account

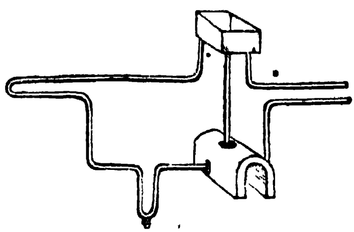
of the cooling of the water in its passage to the boiler. The second method is to supply each story with a separate range of pipes branching out from the main pipe, and returning either together, or separately, into the boiler. The application of this principle, however, requires caution, for if the branch pipes are simply inserted into the side of a vertical ascending pipe, the hot current may pass by, instead of flowing into, them. Some contrivance is, therefore, necessary to delay the motion of the upward current, and to cause it to turn aside at the points required. This may be done by the arrangement shewn in Fig. 54, which is also copied from Mr. Hood's work. Here it will be perceived, that as the water ascends from the boiler, B, it receives a check at b, whereby it tends to flow through the horizontal pipe, at that level. The same also occurs at c, and, by this means, a nearly equal flow of hot water may be obtained. If it be required to cut off the supply of heat from one story, while the others are being heated, this may done by turning a stop-cock at s, by which the heated current is prevented from flowing along the particular branch so closed. But whenever a branch is closed as at s, it is necessary also to close the other end, t, of the same branch, otherwise the water in the descending return pipe, R, being warmer and lighter than that in the branch closed at s, will circulate therein, and thus raise the temperature of the room intended to be kept cool.

Fig. 54.



In some arrangements, the hot ascending current of the vertical main is made to discharge into an open cistern at the top, as in Fig. 55, and from the bottom of this cistern the

Fig. 55.



various flow pipes are made to branch off. By this means, the expense of cocks or valves is avoided; for by driving a wooden plug into one or more of the pipes which open into the cistern, the circulation will be stopped until the apparatus is heated; but, in that case, water will flow back through the return pipe. This, however, may be prevented, by bending a lower portion of the return pipe into the form of an inverted siphon, as shewn in the figure. This will not prevent the circulation when the flow-pipe is open; but if that be closed by a plug in the cistern, the hot water will not return back through the lower pipe. Any sediment that may accumulate in the siphon may be removed, from time to time, by taking off the cap at the lower part of the bend.

In such an arrangement as that shewn in the last two figures, the vertical main pipe need not be of larger diameter than the branches, unless these extend to a very considerable distance, and then the diameter of the main pipe may be somewhat enlarged. It is not, however, desirable to increase the diameter of the main, because it is an object to economise the heat in this pipe, and there are circumstances in which a small main loses less heat than a large one, as, for example, in the arrangement shewn in Fig. 55. If one main pipe, eight inches in diameter, supply four branches in a given time, it is evident, that by reducing the main to four inches in diameter, the water must travel four times faster through the smaller pipe to perform the same amount of work; and, under such circumstances, the water will lose only half as much heat in passing through the small main as it would do in ascending the larger one, for the loss of heat sustained by the water is directly as the time and the surface conjointly.

Hence, in warming by the same boiler two rooms separated from each other by a considerable distance, the pipe connecting the two rooms may be of smaller diameter than the pipes used for diffusing the heat. Thus a pipe of one inch diameter may be used to connect pipes four inches in diameter.

The great specific heat of water, whereby it is enabled to retain its heat for a very long time, has been already shewn (page 42) to be a great advantage of this method of warming buildings. The rate at which this apparatus cools, depends chiefly on the quantity of water contained in it with respect to the amount of surface exposed, and the excess of temperature of the apparatus above that of the surrounding air; but for temperatures below the boiling point, this last circumstance need only be taken into account in estimating the velocity with which this apparatus cools. Now the variation in the rate of cooling for bodies of all shapes, is inversely as the mass divided by the superficies. In cylindrical pipes, the inverse number of the mass divided by the surperficies is exactly equal to the inverse of the diameters; so that, supposing the temperature to be the same in all,

In pipes of . . .	1	2	3	4	inches diameter,
The ratio of cooling will be	4	2	1.3	1	,,

That is, a pipe of one inch in diameter will cool four times as quickly as a pipe of four inches in diameter, and so on. These ratios multiplied by the excess of heat in the pipes above that of the surrounding air, will give the relative rates of cooling for different temperatures below 212°; but if the temperatures be the same in all, the simple ratios given above will shew their relative rate of cooling without multiplying by the temperatures.

These calculations supply practical rules for estimating the size of the pipes under different circumstances. If the heat be required to be kept up long after the fire is extinguished, large pipes should be used; if, on the contrary, the heat is not wanted after the fire is put out, then small ones will answer the purpose. Pipes of larger diameter than four inches should

never be used, because they require a very long time in being heated to the proper temperature. Pipes of four inches in diameter are well adapted for hot-houses, green-houses, and conservatories. Pipes of two or three inches may be used for warming churches, factories, and dwelling-houses; such pipes retain their heat for a sufficient length of time, and they can be more quickly and more intensely heated than larger pipes, so that, on this account, a smaller quantity of pipe will often suffice.

With respect to the quantity of pipe required for warming a building of ascertained size, it is necessary to bear in mind the rate at which a given quantity of hot water, in an iron pipe, will impart its heat to the surrounding air. Now, it has been shewn by Mr. Hood, that the water contained in an iron pipe four inches in diameter internally, and four and a half inches externally, loses .851 of a degree of heat per minute when the excess of its temperature is 125° above that of the surrounding air; and, as one cubic foot of water in losing 1° of its heat will raise the temperature of 2,990 cubic feet of air the like extent of 1°, so one foot length of four-inch pipe will heat 222 cubic feet of air 1° per minute, when the difference between the temperature of the pipe and the air is 125°.

We must now take into account the loss of heat per minute arising from the cooling power of glass, ventilation, radiation, cracks in doors and windows, and other causes. An allowance of from three and half to five cubic feet of air ought to be made per minute for each person in the room, so that, for the purposes of respiration, this quantity will have to be discharged, and an equal supply of air brought in to be warmed.

One square foot of glass will cool 1.279 cubic feet of air as many degrees per minute as the internal temperature of the room exceeds the temperature of the external air. If the difference between them be 30°, the 1.279 cubic feet of air will be cooled 30° by each square foot of glass, that is, as much heat as is equal to this will be given off by each square foot of glass.

From these and other calculations, for which we must refer to Mr. Hood's able work, the following corollary is drawn:— "The quantity of air to be warmed per minute in habitable rooms and public buildings, must be three and a half cubic feet for each person the room contains, and one and a quarter cubic feet for each square foot of glass. For conservatories, forcing-houses, and other buildings of this description, the quantity of air to be warmed per minute must be one and a quarter cubic feet for each square foot of glass which the building contains. When the quantity of air required to be heated has been thus ascertained, the length of pipe which will be necessary to heat the building, may be found by the following rule:—multiply 125 (the excess of temperature of the pipe above that of the surrounding air) by the difference between the temperature at which the room is purposed to be kept when at its maximum, and the temperature of the external air; and divide this product by the difference between the temperature of the pipes and the proposed temperature of the room; then, the quotient thus obtained, when multiplied by the number of cubic feet of air to be warmed per minute, and this product divided by 222 (the number of cubic feet of air raised 1° per minute by one foot of 4-inch pipe) will give the number of feet in length of pipe four inches diameter, which will produce the desired effect."

When 3-inch pipes are used, the quantity of pipe required to produce the same effect will, of course, be different. To obtain it, the number of feet of 4-inch pipe obtained by the above rule must be multiplied by 1.33. If 2-inch pipe be used, the quantity of 4-inch pipe must be multiplied by two.

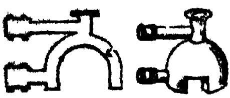
If we wish to determine the quantity of pipe required to maintain a constant temperature of 75° in a hot-house, we must suppose the external air occasionally to fall as low as 10°, and calculate from this temperature. The amount of heat to be supplied by the pipes is obviously that which is expended by the glass, the cooling power of which is exactly proportioned to the difference between the internal and the

external temperature, the actual cubical contents of the house making no difference in the result. If such a house have 800 square feet of glass, it can easily be calculated from the preceding data, that this quantity will cool down 1,000 cubic feet of air per minute from 75° to 10°, which will require 292 feet of 4-inch pipe. If the maximum temperature of the pipe be 200°, and the water be at 40° before lighting the fire, the maximum temperature will be attained in about four hours and a half; with 3-inch pipe in about three hours and a quarter; and with 2-inch pipe in about two hours and a quarter; depending, however, upon the structure of the furnace, and the quantity of coal consumed. If the external temperature be higher than 10°, the effect will be produced in a proportionally shorter time.

In churches and large public rooms, with an average number of doors and windows, and moderate ventilation, a more simple rule will apply for ascertaining the quantity of pipe required. Where a number of persons are assembled, a large amount of heat is generated by respiration, so that a very moderate artificial temperature is sufficient to prevent the sensation of cold. In such a case, the air does not require to be heated above 55° or 58°, and the rule is to take the cubical measurement of the space to be heated, and dividing this by 200, the quotient will be the number of feet of 4-inch pipe required.

The efficiency of any form of hot water apparatus will, of course, greatly depend on the boiler, which ought to be so constructed as to expose the largest amount of surface to the fire in the smallest space; to absorb the heat from the fuel, so that as little as possible may escape up the chimney; to allow free circulation of the water throughout its entire extent, and not be liable to get out of order by constant use. A variety of boilers are figured in Mr. Hood's work, and their respective merits considered on scientific grounds. One of these boilers is shewn in Fig. 56. It is of cast iron, and the part exposed to the fire is covered with a series of ribs two

Fig. 56.



inches deep, and about one-fourth or three-eighths of an inch thick, radiating from the crown of the arch at an average distance of two inches from each other. These ribs greatly increase the surface exposed to the fire, exactly where the effect is greatest; for being immediately over the burning fuel, it receives the whole of the heat radiated by the fire. The form of this boiler being hemispherical, will also expose the largest amount of surface within a given area. The boiler shewn in Fig. 54, being of wrought iron, and, therefore, thinner than cast iron, absorbs the greatest amount of heat from the fuel.

With respect to the size of the boiler, it has been shewn by experiment that four square feet of surface in an iron boiler will evaporate one cubic foot of water per hour when exposed to the direct action of a tolerably strong fire. The same extent of heating surface which will evaporate one cubic foot of water per hour from the temperature of 52°, will be sufficient to supply the requisite amount of heat to 232 feet of 4-inch pipe, the temperature of which is required to be kept 140° above the surrounding air; or one square foot of boiler surface exposed to the direct action of the fire, or three square feet of flue surface, will supply the necessary heat to about 58 superficial feet of pipe, or, in round numbers, one foot of boiler to 50 feet of pipe. But as this is the maximum effect, a somewhat larger allowance ought in general to be made. If the difference of temperature be 120° instead of 140°, the same surface of boiler will supply the requisite amount of heat to one-sixth more pipe, and if the difference be only 100°, the same boiler will supply above one-third more pipe than the quantity stated.

With respect to the furnace, the rate of combustion of the fuel will depend chiefly on the size of the furnace-bars, provided the furnace door be double and fit tightly. The ash-pit should also be provided with a door to exclude the excess of the fire is required to burn slowly. A dumb-plate

should also be provided, to cause the combustion to be most active at the hinder part of the furnace instead of directly under the boiler. The fuel will thus be gradually coked, the smoke consumed, and the fuel economised.

In an apparatus containing 600 feet of 4-inch pipe, the area of the furnace bars should be 300 square inches, so that 14 inches in width and 22 inches in length will give the amount of surface required. To obtain the greatest heat in the shortest time, the area of the bars should be proportionally increased, so that a larger fire may be obtained. The fire ought at all times to be kept thin and bright, and to obtain a good effect from the fuel, one pound weight of coal ought to raise 39lbs of water from 32° to 212°.*

The best kind of pipes for hot water apparatus are those with socket-joints, flange-joints having long been out of use for this purpose Where the socket-joints are well made, there is no fear of leakage, for the pipes themselves will yield before he joints will give way, or before the faucet end of one pipe can be drawn out of the socket of the other. The joints must be well caulked with spun yarn, and filled up with iron cement, or with a cement made of quicklime and linseed oil

Soft or rain-water ought always to be used in the hot water apparatus, because, if hard water be used, its salts will form a sediment or crust in the boiler, and interfere with its action. But as there is very little evaporation from this kind of apparatus, the boiler will not require cleaning out for years, if a moderate degree of attention be bestowed on the water employed.

When the apparatus is not in use, care must be taken to prevent the water from freezing in the pipes, or the sudden expansive force of the water in freezing may crack them. If

* In the Cornish engines 65½, and even 85lbs of water have been raised from 32° to 212°, by the combustion of one pound of coal. This is a far more favourable result than has been produced with any other oilers or qualities of coal, than those employed in the experiment.

the apparatus is not likely to be used for some time during winter, it is better to empty the pipes than incur the risk of freezing. It has been proposed to fill the pipes with oil instead of water, and as the boiling point of oil is nearly three times higher than that of water, it was thought that a temperature of 400° might be safely given to the pipes. It was found, however, that the oil at high temperatures became thick and viscid, and at length changed into a gelatinous mass, completely stopping all circulation in the pipes.

In the forms of apparatus to which the preceding details refer, the temperature of the water never rises to the ordinary boiling point (212°); but we have now to notice a method, in which the temperature of the water is often beyond 300°; this is the high-pressure method contrived by Mr. Perkins.* In its simplest form, the apparatus consists of a continuous or endless pipe, closed in all parts, and filled with water. There is no boiler to this apparatus, its place being supplied by coiling up a portion of the pipe (generally one-sixth of the whole length) and arranging this in the furnace. The remaining five-sixths of the pipe are heated by the circulation of the hot water, which flows from the top of the coil, and cooling in its progress through the building, returns to the bottom of the coil to be re-heated. The diameter of the pipe is one inch externally, and half an inch internally, and is formed of wrought iron. The coil in the furnace being entirely surrounded by the fire, the water is quickly heated, and becoming also filled with innumerable bubbles of steam, these impart a great specific levity to the ascending current. At the upper part of the pipe, the steam bubbles condense into water, and uniting with the column in the return pipe, which is comparatively cool, the descent is rapid in proportion to the expansion of the water in the ascending column, or, in other words, ac-

* One authority on this subject, is Mr. Richardson's *Treatise on the Warming and Ventilation of Buildings, showing the advantages of the Improved System of Heated Water Circulation, &c.* Second Edition. London, 1839.

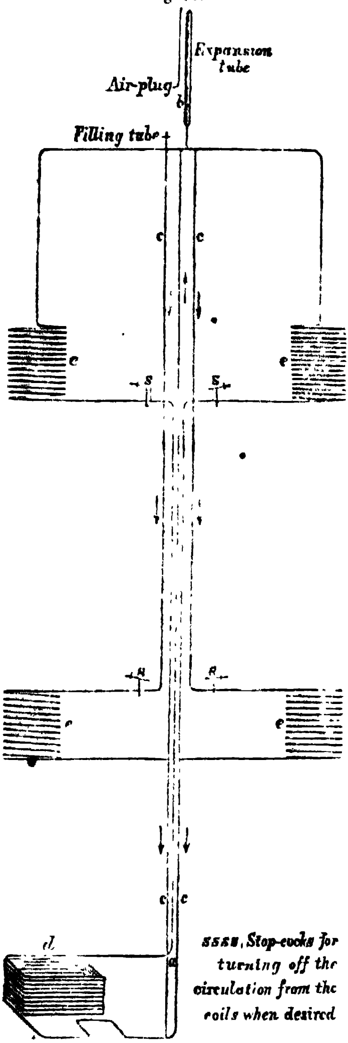
cording to the relative specific gravities of the two columns of water.

As the expansive force of water is almost irresistible, in consequence of its extremely limited elasticity, it is necessary in the high pressure apparatus to make some provision for the expansion of the water when heated. The necessity for this will appear from the fact, that water heated from 39.45° (the point of greatest condensation) to 212°, expands about $\frac{1}{23}$ part of its bulk; and the force exerted on the pipes by this expansion, would be equal to 14,121lbs. on the square inch. The method adopted, is to connect a large pipe, called the expansion pipe, 2½ inches diameter, with some part of the apparatus, either horizontally or vertically. It should be placed at the highest point of the apparatus, and at the bottom of the expansion pipe is inserted the filling pipe through which the apparatus is filled. While the apparatus is being filled with water, the expansion tube is left open at the top; water is then poured in through the filling tube, and as it rises in the pipes, drives out the air before it. When the pipes are full, the filling pipe and the expansion tube are carefully closed with screw plugs. It is important to expel all the air from the pipes, and this is done, in the first instance, by pumping the water repeatedly through them. The expansion pipe is, of course, left empty, as its use is to allow the water in the pipes to expand on being heated, and thus prevent the danger of bursting. From 15 to 20 per cent. of expansion space is generally allowed in practice.

The furnace is generally so arranged in the building required to be heated, as to allow the tube proceeding from the top of the coil to be carried straight up at once to the highest level at which the water has to circulate; here the expansion tube is situated, and from this point, two or more descending columns can be formed, which, after circulating through different and distant parts of the building, unite at length in one pipe, just before entering the bottom of the coil in the furnace.

The whole arrangement will be better understood by referring to Fig. 57, in which *a* is the ascending column; *b*, the expansion tube; *c*, the descending columns; and *d*, the coil in the furnace.

Fig. 57.



The heat is communicated to the air of the rooms from the external surface of the pipes, which are coiled up as at *e e*, and placed within pedestals, ranged about the room with open trellis work in front, or they may be sunk in stone floors, placed behind skirtings, or in the fire places of each floor, the flues being stopped, or arranged in any other convenient manner.

In consequence of the great internal pressure, which these tubes have to sustain, considerable care is required in their manufacture. They are made of the best wrought iron, rolled into sheets a quarter of an inch thick, and of the proper width. The edges are then brought nearly together, the whole length of the iron, which is generally about 12 feet. In this state it is placed in a furnace, and heated to a welding heat. One end is then grasped by an instrument firmly attached to an endless chain, revolving by steam power, and a man applies

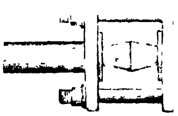
a pair of circular nippers, which, when closed, press the tube into the required size, and which he holds firmly while the tube is drawn through them by the engine. The edges are thus brought into perfect contact, and are so completely welded after passing two or three times through the nippers, that a conical piece of iron driven into the end of the tube will not open it at the joint sooner than at any other part.

When the tubes are screwed together at each end, they are proved by hydrostatic pressure, with a force equal to 3,000lbs. on the square inch of internal surface. In this state they are sent to London, and such is the purity and ductility of the iron, that the tubes can be easily bent, while cold, into coils of different sizes and shapes, as required.

When the tubes are properly arranged and fixed in the building, the whole apparatus is filled with water by a force pump, and subjected to considerable pressure, before lighting the fire. In this way, faulty pipes or leaky joints are detected.

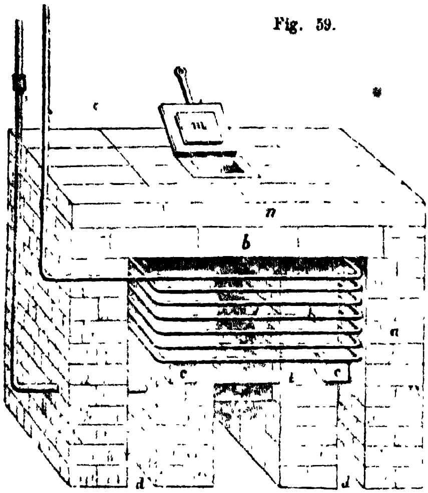
The tubes are joined by placing the ends within a socket, forming a right and left hand screw, the edge of one tube having been flattened, and the other sharpened : they are then screwed so tightly together, that the sharpened edge of one pipe is indented in the flattened surface of the other. Another method of connecting the pipes is by a cone joint. A double cone of iron is inserted into the ends of the pipes to be joined, and is made tight by two screw bolts, as shewn in Fig. 58. This joint is quickly made, and is very strong.

Fig. 58.



The furnace varies in form and dimensions according to circumstances ; but a very common arrangement is shewn in Fig. 59. The size is about three and a half feet square, increasing to six feet, according to the extent of pipe connected with it. The fire occupies a small space in the centre, raised

Fig. 59.



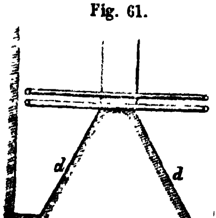
about one foot from the ground, and the fuel is supplied through the hopper door, *m*, at the top. The outer casing, *a*, is of common brick-work; *b b*, are Welsh fire-lumps; *c c*, are fire-bricks, supporting the coil, *k*; *d d*, reservoirs for the dust and soot, which would otherwise clog the coil; *g*, bearing bars for the grate; *h*, the grate: the fire-door is double, and there are also doors to the ash-pit and dust reservoirs.

Fig. 60.

Fig. 60 shews the descending tube entering the fire-chamber, and passing through the bearing bars, *g g*, of the grate, *h*. Fig. 61 is a section of the back well or reservoir, *d d*, formed so as to support the coil, and to cause the soot and dust to fall to the bottom.

In this arrangement of the furnace, the ignited coal is surrounded on three sides by a thickness of nine-inch fire-brick, or Welsh lumps; the hopper door is also placed in one of these lumps; the coil is contained in a chamber round the fire-brick, four and a half inches wide; the pipe enters this chamber, passing through the bearing bars of the grate, which tends to preserve the grate from burning; the pipe passes out from the top of the coil, at the upper part of the chamber.

Fig. 61.



The smoke passes through the chamber containing the pipes, and escapes through an opening at the back. The coil is in actual contact with the fire only in front. The best fuel for this furnace is coke or Welsh hard coal, such as is not liable to clog. The furnace may be placed in a cellar, or be com pletely removed from the building to be warmed. The heat of the furnace can be moderated by closing the ash-pit door, and opening the furnace door, or the reservoir doors, so as to lessen the draught and admit cold air to the coil.

In the apparatus erected at the British Museum for warming the print-room and the bird-room, the furnace is in a vault in the basement story, and the pipes, entering a flue, are carried up about forty feet to two pedestals, one in each room; one containing 360 feet of pipe, and the other 400 feet. About 140 feet of pipe are employed in the flow and return pipes in the flue, and 150 feet are coiled up in the furnace. In this way, 1,050 feet of pipe are employed: the apparatus is very powerful, and supplies the requisite amount of heat. The print-room is about 40 feet long, by 30 feet wide, and the ceiling contains large sky-lights. The temperature of 65° can easily be maintained in this room during winter. The fire is lighted at 6, A.M., and is allowed to burn briskly till sufficient heat is produced in the rooms, when the damper in the flue is partially closed. A slow fire is thus maintained: at 11, A.M., a fresh supply of fuel is added, and this supports the fire till 4, P.M., when all the fires at the Museum are extinguished.*

The above details will suffice to show the nature and application of this apparatus. For its adaptation to houses and public buildings, under a greater variety of circumstances, we must refer to Mr. Richardson's work. We fully agree with him, that in any building where this apparatus is intended to

* Mr. Hood states, on the contrary, that, owing to the smallness of the pipes in the high-pressure apparatus, the coil cools so rapidly when the fire slackens in intensity, that the heat of the building is materially affected by the least alteration in the force of the fire, instead of maintaining that permanence of temperature which is so peculiarly the characteristic of the hot-water apparatus with large pipes.

be erected, it ought not to be introduced as an after-thought. "It should be remembered, that as its complete success, and its economical character, depend, in a great measure, upon due consideration of its benefits being given at the commencement of a building, so it ought, in future, to engage the primary consideration of the architect and builder."

It is, however, of great importance, to ascertain whether this apparatus is perfectly safe, for even a doubt on the subject must be fatal to its general introduction. The average temperature of the pipes is stated to be generally about 350°; but a very material difference in temperature, amounting sometimes to 200° or 300°, is said to occur in different parts of the apparatus, in consequence of the great resistance which the water meets with in the numerous bends and angles of this small pipe. The temperature of the coil will, of course, give the working effect of the apparatus, but the temperature of any part of the pipe will furnish data for estimating its safety; for whatever is the temperature, and, consequently, the pressure in the coil, must be the pressure on any other part of the apparatus; for by the law of equal pressures of fluids, an increased pressure at one part will generate an equally increased pressure at every other part of the system.

A very elegant method of ascertaining the temperature of a heated surface of iron or steel, consists in filing it bright, and then noting the colour of the thin film of oxide which forms thereon.* Mr. Hood states, that in some apparatus, if that part of the pipe which is immediately above the furnace be filed bright, the iron will become of a straw colour, showing a temperature of about 450°. In other instances, it will be-

* Steel becomes	a very faint yellow	at	430° Fahr.
„	pale straw colour	„	450°
„	full yellow	„	470°
„	brown	„	490°
„	brown, with purple spots	„	510°
„	purple	„	530°
„	blue	„	550°
„	full blue	„	560°
„	dark blue, verging on black	„	600°

come purple=about 530°, and, in some cases, of a full blue colour=560°. Now, as there is always steam in some part of the apparatus, the pressure can be calculated from the temperature, and a temperature of 450°= a pressure of 420lbs. on the square inch; 530°=900lbs.; and 560°=1,150lbs. per square inch.

Although these pipes are proved, at a pressure of nearly 3,000lbs. per square inch, and the force required to break a wrought iron pipe of one inch external, and half an inch internal diameter, requires 8,822lbs. per square inch on the internal diameter, yet these calculations are taken for the cold metal. By exposing iron to long continued heat, it loses its fibrous texture, and acquires a crystalline character, whereby its tenacity and cohesive strength are greatly weakened.

In order to make this apparatus safe, Mr. Hood suggests that, instead of hermetically sealing the expansion-pipe, it should be furnished with a valve, so contrived, as to press with a weight of 135lbs. on the square inch. This would prevent the temperature from rising above 350° in any part: the pressure would then be nine atmospheres, which is a limit more than sufficient for any working apparatus where safety is of importance.

But, supposing the apparatus were to burst in any part, the effects would, by no means, resemble those which accompany the explosion of a steam boiler. One of the pipes would, probably, crack, and the water, under high pressure, escaping in a jet, a portion of it would be instantly converted into steam, while that which remained as water would sink to 212°. This would have the effect of scalding water under ordinary circumstances, but the high pressure steam would not scald, because its capacity for latent heat is greatly increased by its rapid expansion, on being suddenly liberated, so that instead of imparting heat, it abstracts heat from surrounding objects. The only real danger that would be likely to ensue, would be from the jet of hot water, and this must, in any case, be of trifling amount.

PART II.

CHAPTER I.

ON THE GENERAL PRINCIPLES OF VENTILATION; AND THE METHOD OF VENTILATING BUILDINGS, SHIPS, ETC., BY SPONTANEOUS ACTION, AND BY MECHANICAL CONTRIVANCES.

REAUMUR remarks, "Ce que la Nature apprend est sçu de bonne heure," and as Nature is the best, as well as the earliest, teacher, we take our first example, in the history of ventilation, from the lower animals, and, we venture to assert, that a more difficult, or, apparently, more hopeless problem, does not exist in our rooms and crowded assemblies, our mines and ships, than in the case about to be proposed.

Imagine a dome-shaped building, perfectly air-tight, except through a small hole at the bottom, capable of containing thirty or forty thousand animals, full of life and activity; every portion of the enclosed space that can be spared being filled with curious machinery; the problem is, how to warm and ventilate such a space, so as to maintain a proper temperature, and yet to give to every individual within it a proper supply of air.

Now this is the condition of a common bee-hive, and we may remark, that if, with all our machines, and contrivances, and scientific resources, the combined operation of warming and ventilating a room be difficult or unsatisfactory, how infinitely more so must be that of a small bee-hive, crowded with bees, the greater part of the interior filled up with combs of waxen cells, and only one small opening for the ingress and

egress of the inhabitants, or for the escape of foul air and the entrance of fresh.

In a common hive, there is absolutely no other door or window, or opening, than this small entrance hole; for, on taking possession of a new hive, the bees stop up all the cracks and chinks, with a resinous substance named *propolis*, for the purpose of keeping out insect depredators; and the proprietor, with the same object, generally plasters the hive to the stool, and, in order to keep off the rain, covers it with a heavy straw cap, or turns a large pan over it.

It must not be supposed that, because the vitality of insects is greater than that of warm-blooded animals, bees are not affected by the same agencies which affect us, for they are so, and in a similar manner: they fall down apparently dead, if confined in a close vessel; they perish in gases which destroy us; they perspire and faint with too much heat; and are frozen to death by exposure to too much cold.

Huber introduced some bees into the receiver of an air-pump. They bore a considerable rarefaction of the air without any apparent injury: on carrying it further, they fell down motionless, but revived on exposure to the air. In another experiment, three glass vessels, of the capacity of sixteen fluid ounces, were taken; 250 worker bees were introduced into one, the same number into another, and 150 males into the third. The first and the third were shut close, and the second was partially closed. In a quarter of an hour, the workers in the close vessel became uneasy; they breathed with difficulty, perspired copiously, and licked the moisture from the sides of the vessel. In another quarter of an hour, they fell down apparently dead. They revived, however, on exposure to the air. The males were affected more fatally, for none survived; but the bees in the vessel which admitted air, did not suffer. On examining the air in the two close vessels, the oxygen was found to have disappeared, and was replaced by carbonic acid: other bees, introduced into it,

perished immediately. On adding a small portion of oxygen gas to it, other bees lived in it; but they became insensible instantly on being plunged into carbonic acid, and revived on exposure to the air: they perished irrecoverably in nitrogen and hydrogen gases. Similar experiments, performed with the eggs, the larvæ, and the nymphs of bees, proved the conversion of oxygen into carbonic acid, in all three states. The larvæ consumed more oxygen than the eggs, and less than the nymphs. Eggs, put into foul air, lost their vitality. Larvæ resisted the pernicious influence of carbonic acid better than the perfect insect would have done, but the nymphs died almost instantly therein.

These, and many other analogous experiments, prove that the respiration of bees has a similar vitiating effect upon a confined atmosphere, as the respiration of larger animals, and that bees require constant supplies of fresh air, in the same manner as other living creatures. They also require their dwelling to be kept moderately cool. When from any circumstance, such as exposure to the sun, overcrowding, or the excitement produced by fear, anger, or preparation for swarming, the temperature of the hive is greatly raised, the bees evidently suffer. They often perspire so copiously, as to be drenched with moisture; and on fine summer nights, thousands of them may be seen hanging out in festoons and clusters, for the purpose of relieving the crowded state of the hive.

On inquiring into the method adopted by the bees for renewing the air of the hive, Huber was struck by the constant appearance of a number of the workers arranged on each side of the entrance hole, a little within the hive, incessantly engaged in vibrating their wings. In order to see what effect a similar fanning would produce on the air of a glass receiver, containing a lighted taper, M. Senebier advised him to construct a little artificial ventilator, consisting of eighteen tin vanes. This was put into a box, on the top of which was adapted a large

cylindrical vessel, of the capacity of upwards of 3,000 cubic inches. A lighted taper, contained in this vessel, was extinguished in eight minutes; but, on restoring the air, and setting the ventilator in motion, the taper burnt brilliantly, and continued to do so as long as the vanes were kept moving. On holding small pieces of paper, suspended by threads, before the aperture, the existence of two currents of air became evident; there was a current of hot air rushing out, and, at the same time, a current of cold air passing in. On holding little bits of paper or cotton near the hole of the hive, a similar effect was produced: they were impelled towards the entrance by the in-going current, and when they encountered the out-going current, they were repelled with equal rapidity.

These two currents are established in the hive, by the fanning motion of the bees' wings. The worker bees perform the office of ventilators, and the number, at one time, varies from eight or ten to twenty or thirty, according to the state of the hive and the heat of the weather. We have frequently watched their proceedings with interest. They station themselves in files, just within the entrance of the hive, with their heads towards the entrance, while another and a larger party stand a considerable way within the hive, with their heads also towards the entrance. They plant their feet as firmly as possible on the floor of the hive, stretching forward the first pair of legs, extending the second pair to the right and left, while the third, being placed near together, are kept perpendicular to the abdomen, so as to give that part a considerable elevation; then uniting the two wings of each side by means of the small marginal hooks with which they are provided, so as to make them present as large a surface as possible to the air, they vibrate them with such rapidity, that they become almost invisible. The two sets of ventilators, standing with their heads opposed to each other, thus produce a complete circulation of the air of the hive, and keep down the temperature to that point which is fitted to the nature of the animal. When a higher temperature is required at one particular spot,

as, for example, on the combs containing the young brood, the nurse bees place themselves over the cells, and by increasing the rapidity of their respirations, produce a large amount of animal heat just where it is wanted. The carbonic acid, and other products of respiration, are got rid of by ventilation.

The laborious task of ventilating the hive is seldom or never intermitted in the common form of hive, either by day or by night, during summer. There are separate gangs of ventilators, each gang being on duty for about half an hour. In winter, when the bees are quiet, and their respiration only just sufficient to maintain vitality, the ventilating process is not carried on ; but by gently tapping on the hive, its inmates wake up, increase the number of their respirations, and, consequently, the temperature of the hive, to such a degree, that the air becomes intolerably hot and vitiated. To remedy this, a number of worker bees go to the entrance of the hive, and begin to ventilate the interior as laboriously as in summer, although the open air be too cold for them to venture out.

Bearing in mind the details given in the introduction and the conclusion arrived at, (page 11), that the animal frame is a true apparatus for combustion, we can understand how bees regulate the temperature of their hive : when greater heat is wanted, they increase the rapidity of their respirations, or. in other words, they burn more carbon ; but they get rid of the products of combustion, and also prevent the heat from accumulating, by the process of ventilation. Bees, in general, maintain a temperature of 10° or 15° above that of the external air ; but, at certain periods, this temperature is greatly increased. Mr. Newport observed, in the month of June, when the atmosphere was at 56° or 58°, that the temperature of the hive was 96° or 98°. This high temperature arose from the nurse bees incubating on the combs, and voluntarily increasing their heat by means of increased respiration. In winter, on the contrary, when only just sufficient heat is

required to maintain vitality, less carbon is burnt, and the temperature of the hive is accordingly low. In one observation by Mr. Newport at 7.15, A.M., on the 2nd January, 1836, when there was a clear intense frost, and the thermometer in the open air stood a little above 17°, a thermometer permanently fixed in the hive, marked a temperature of 30°, or two degrees below the freezing point. The bees were roused by tapping on the hive, and in the course of sixteen minutes, the thermometer rose to 70°, or 53° above the temperature of the external air. On another occasion, when the temperature of the hive had been raised to about 70°, the external air being at 40°, the bees soon cooled it down to 57° by their mode of ventilation, and kept it at that point as long as the hive continued to be excited.

By this process of ventilation also, bees get rid of noxious odours in the hive. Huber found that, on introducing into the hive some penetrating vapour, disagreeable to the bees, they always increased the amount of ventilation, until they got rid of it. Humble-bees adopt the same method of dispelling pernicious odours; but it is remarkable, that neither their males, nor those of domestic bees, seem capable of using their wings as ventilators. "Ventilation is, therefore," says Huber, "one of the industrial operations peculiar to the workers. The Author of Nature, in assigning a dwelling to those insects where the air can hardly penetrate, bestows the means of averting the fatal effects which might result from the vitiation of their atmosphere. Perhaps the bee is the only creature entrusted with so important a function, and which indicates such delicacy in its organization."

The circumstances under which our rooms are placed, are far more favourable to ventilation than the bee-hive. Whether the ventilation be left to chance, or whether any special apparatus be erected for the purpose, the foul vitiated air must be got rid of, and fresh air, adapted to the purposes of respiration, admitted in sufficient quantity, that is, at the rate of about four cubic feet per minute for each individual in the

room. The air must leave the room at certain openings, or be drawn out of it thereby at this rate, while a similar amount of fresh air must enter to supply the loss, or, to speak more accurately, the force or impetus of the incoming air ought slightly to compress the air of the room, and assist the efflux of the vitiated air, and this, in its turn, ought to be so heated, as to have a certain amount of ascentional force over that of the incoming air. In some cases, mechanical means are necessary to expel the air, such as fanners, bellows, pumps, &c., but it is generally more convenient, as well as economical, to trust to the natural method of getting rid of the vitiated air, by making certain ventilating tubes or openings at the highest point of the room towards which the hot air tends to flow.*

The same cause which produces the draught of common chimneys, and of the glass chimneys of our oil and gas lamps will, if circumstances be favourable, set in motion and discharge the vitiated air of our rooms, at the same time that it brings in the fresh. For example, the air of a common chimney, under the influence of the fire, expands according to a law applicable to all gases, namely, $\frac{1}{480}$ of its volume for each degree of Fahrenheit's scale from 32° to 212°. Now if a chimney or ventilating flue were ten feet high, and the temperature of the column of air within it were raised 20° above the temperature of the external air, the expansion would be $\frac{20}{480}$ths, or $\frac{1}{24}$th of its bulk. This would so far diminish the specific gravity of the heated column, that it would require $10\frac{1}{2}$ feet thereof to balance a column of the external air of

* It may be as well to mention, that some writers have divided artificial ventilation into two branches, which they call *plenum* and *vacuum*. By the first, air is forced, by mechanical contrivances, into the interior of a building, and the vitiated air is allowed to escape by openings contrived for the purpose; by the second, the vitiated air is drawn out of the building by means of mechanical contrivances, or through the agency of heat artificially excited, and the fresh air thus finds an entrance through channels adapted to the purpose.

10 feet. It has been already stated (page 83), that the velocity of efflux is equal to the velocity of a heavy body falling through the difference in height between the two columns; and in the case before us, the difference of five inches is equal to 5.174 feet per second, or 310 feet per minute; and this is the velocity with which a heated column of air would be forced through the ventilating tube or chimney; and supposing the dimensions of this to be one foot square, then 310 cubic feet of air would escape per minute. This, however, is the theoretical amount, which does not take into account the retarding effects of friction arising from the roughness of the tube, or any angles or bends in it, or the increased density of the hot air from the presence of carbon from the fuel, in a minutely divided state. In practice, it is usual to allow from $\frac{1}{4}$th to $\frac{1}{3}$rd for the effects of friction.

As the velocity of a falling body, in a second of time, is known to be eight times the square root of the height of the descent, in decimals of a foot, so the velocity of discharge per second, through vent tubes or chimneys, may be briefly stated as equal to eight times the square root of the difference in height of the two columns of air, in decimals of a foot. This number, reduced one-fourth for friction, and the remainder multiplied by 60, will give the true velocity of efflux per minute; and the area of the tube, in feet, or decimals of a foot, multiplied by this last number, will give the number of cubic feet of air discharged per minute.

In estimating the total height of a column of heated air, we must calculate the total vertical height from the floor of the room to be ventilated to the top of the tube, where it discharges into the open air. All horizontal bends and angles may be neglected, for these make no difference in the vertical height, but only increase the amount of friction, and deprive the heated column of a portion of its ascentional force, by cooling. As the vertical height of the column gives the velocity of discharge in the ratio of the square root of the height

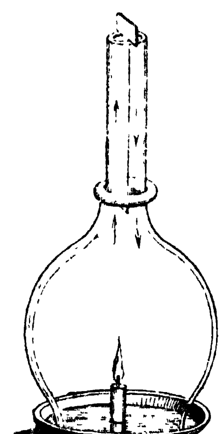
of the column, it is necessary, where several vent tubes be employed, that they all be of the same vertical height, or the highest vent will prevent the efficient action of the lower ones, so that there may actually be a smaller discharge through two tubes than through one only.

So also, when several openings are made above the level of the floor of a room, the highest may be the only one capable of acting as an abduction tube, the other lower openings often serving as induction tubes, discharging cold air into the room instead of taking it out, and, in doing so, lower the temperature of the hot vitiated air, and prevent it from escaping; thus not only causing the bad air to be breathed over again, but filling the room with unpleasant draughts. But if the highest abduction tube be too small to carry off the requisite quantity of hot air, the tube next below it in elevation at any part of the room will act as an abduction tube.

If the lower openings for the admission of cool fresh air be too small in proportion to those for the escape of the hot air, a current of cold air will descend through one part of the hot air tube, and the hot air will ascend through another part of the same tube, an effect which we have already seen takes place in the ventilation of a bee-hive. This effect may also be shewn by a very pleasing experiment. Place a lighted taper in a flat dish, and cover it with a glass receiver, furnished with a long glass chimney placed immediately over the flame. If the bottom of the receiver does not come into very close contact with the dish, enough air will enter to support combustion, and the draught or current of hot air will escape up the chimney, and the taper will continue to burn for any length of time. If we now shift the receiver a little on one side, so that the flame may not be immediately under the chimney, the products of combustion will impinge upon the glass, and cooling down and mingling with the air of the receiver, will contaminate it so much, that the taper immediately begins to burn dimly, and will soon be extinguished.

On bringing the chimney over the flame, it will speedily improve in appearance; the smoke and other products of combustion will be rapidly discharged, and the receiver will become bright and transparent as before. But suppose we cut off all communication with the external air from below by pouring a little water into the dish, so as to cover the mouth of the receiver, we shall then have the case of a room which is provided with a vent tube near the ceiling, but has no provision for admitting fresh air from any lower openings; in such case, the fresh air will seek to enter by the ventilating tube. If this be large enough, the outgoing hot air and the incoming cool air will divide the tube into two parts. But if, as in the experiment before us, the ventilating tube or chimney be too narrow, the hot and cold currents will interfere with each other; the tendency of the hot air to rise and of the cold air to descend, will prevent the escape of the one and the entrance of the other, and the taper will soon be extinguished for want of fresh air. But if the chimney be divided into two portions by a flat strip of tin plate passed down it, as in Fig. 62, and the taper be lighted and placed in its former position, it will continue to burn for any length of time; for, by this arrangement, the two currents of hot and cold air are prevented from interfering with each other; the hot air will pass up one channel and escape, and the cold air will descend the other channel to feed the flame. By holding a piece of smoking paper or the glowing wick of a taper on one side of the chimney, the smoke will be drawn down, thereby indicating the descending current of cool air; while, on the other side, the smoke will be driven up by the ascending current of heated air.

Fig. 62.



In the same manner these counter currents may be frequently noticed in churches and other crowded places, where due provision is seldom made for the entrance of fresh air, and the escape of the foul. It is usual in summer to mitigate the effects of the hot vitiated atmosphere, by throwing open the windows. A portion of the foul air, it is true, escapes by these channels, but a counter current immediately sets in through each of them, exposing the persons near them to the dangerous effects of draught, and also cooling the foul air which is seeking to escape, and sending it down to be breathed over again.

Now, in order that these open windows or any other ventilating openings be effective, it is necessary that the lower openings for the admission of fresh air be as numerous, or, at least, as large as the upper ones, and larger if possible. By making these lower openings, or induction pipes, or doors, or valves, or any other contrivances both numerous and capacious, the entering current is broken up and divided, and cold draughts are avoided. This remark is equally applicable to fresh air, which has been previously warmed by any artificial process; for, by admitting it into the room through numerous channels, it distributes its warmth more equally, and does not rise to the ceiling too rapidly.

Ventilation is more difficult in summer than in winter, because, in warm weather, the difference between the internal and the external temperature is much less than in cold weather. In all cases of spontaneous ventilation, it will, therefore, be necessary in summer to increase the number or the size of the ventilating tubes. When these tubes are constructed, their number and size ought to be adapted to the full amount of summer ventilation. In winter, some of them can be closed, and others, if too large, ought to admit of being reduced in size.*

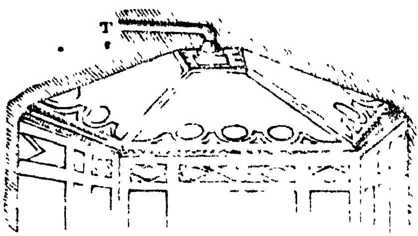
* Perforated zinc is now getting into use as a ventilator. The pane of glass furthest from the fire-place and in the upper row is taken out,

Tredgold, in his work on *Warming and Ventilating* (Second edition. London, 1836), has given some very sensible directions for the ventilation of a church, which, of course, apply equally to any other public building, and, to a certain extent, to private houses. He advises, that the spaces for the admission of cold air be abundantly large, and divided as much as possible; they should be in or near the floor (see Fig. 65), so that the air may not have to descend upon any one; by making the openings large, and covering them on the inside with rather close wire work (sixty-four apertures to the square inch) most of the current may be prevented; and it may be still further prevented by bringing tubes under the paving to admit fresh air into the central parts of the church. Of course these openings must be provided with shutters, so as to close them when desirable. Provision should be made for the escape of the warm air at different parts of the ceiling, through air-trunks furnished with registers. The form of the mouth of the vent tube, is a circular aperture, with a balanced circular register plate, P (Fig. 64), to close it. This plate should be larger than the aperture, in order that the air may be drawn into a horizontal current, for the purpose of taking away the portion of air next the ceiling. If the tube were left without a plate, the air immediately under it would press forward up the tube, and very little of the worst air which collects at the ceiling would escape.

A flat or level ceiling is not well adapted to the purposes of ventilation; but a still worse form of ceiling is that which is divided into coffers, for in these the air collects, gets cooled, and descends. For effective ventilation, ceilings ought always to be dome-shaped, coved, arched, groined, or of the form of a truncated pyramid, as shewn in Fig. 63, so as to rise in the

and its place supplied with a sheet of zinc, having 220 perforations to the square inch. Panes of perforated glass are also abundantly supplied, as well as glass louvres.

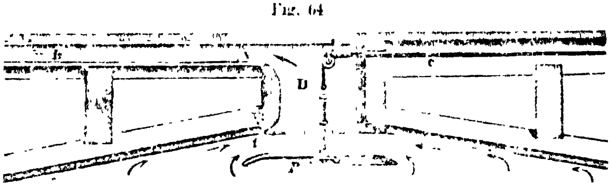
Fig. 63.



centre, and at the centre or most elevated point, the ventilating tube, T, should be placed. When curved lines are not used, ceilings of this form ought always to be adopted; they are not much more expensive than flat ones; they have a better effect, and are vastly superior as far as ventilation is concerned, supposing an opening be made in the central or highest point for the escape of the vitiated air.

As it is not always possible to conduct the vent tube at once in a vertical line from the highest point of the ceiling, there is no objection to giving it a horizontal direction for some distance. In Fig. 64, the vent tube, A B, is horizontal, and is

Fig. 64



conducted between the timbers of a floor. This figure also shews how the timbers may be disposed, so that there may be a rise in the centre without loss of space.* C is a cord passing over a pulley, D, for raising or lowering the register plate, P. This plate is balanced by a weight attached to the

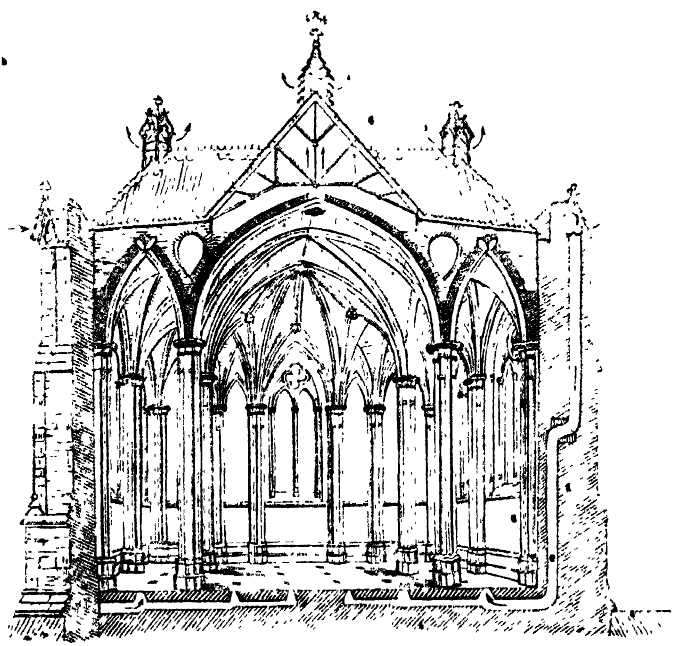
* In Tredgold's figure, the timbers on each side of the ventilating opening, D, are made to dip, as shewn in the dotted line at *t*, (Fig. 64). This ought always, if possible, to be avoided, as it prevents the free passage of the air; and even such a slight impediment as this might cause a stratum of air near the ceiling to cool and descend before it had time to escape up the opening.

lower part of the cord, which passes down nearly to the floor of the room, where it is secured by a hook.

Where the vent tubes can be carried up vertically from the ceiling to the top of the building, it is always better to do so, because the friction of the hot ascending current is thereby diminished. If the vent be made through the ceiling of a church into the space in the roof, and from this space, an air tube be taken up within the steeple or bell-turret, an effectual ventilation may be obtained without adding outlets to the roof. Where external appearance is less regarded, a common louvre-boarded top, for an outlet from the roof, will answer. All side and end windows should be kept closed; for if the apertures at the ceiling be of the proper size, and due provision be made for supplying fresh air, these open windows, as already explained, will diminish, not increase the amount of ventilation. The reason has been already stated why ventilation is difficult to maintain in warm weather. Of course, it becomes especially so in very calm, warm weather. Mr. Tredgold gives a case of this kind:—Suppose we wish to provide ventilation sufficient to prevent the internal air from being of a higher temperature than 5° above that of the external air. Now, if the external air be at 70°, we shall not be able to keep the internal temperature down to 75° with a less escape of air than 2½ cubic feet per minute for each person; because each person will heat, at least, that quantity of air 5° in a minute, at these temperatures When a church contains 1,000 persons, and the height from the floor to the top of the tube is 49 feet, the sum of the apertures that will allow 2,500 cubic feet of air per minute to escape, when the excess of temperature is 5°, must be equal to 12 square feet. If the height be only 30 feet, the size of the aperture must be 14 square feet nearly. When the ceiling is level, this area should be divided among five or more ventilators, disposed in different parts of the ceiling; but in a vaulted or arched roof, three are recommended to be placed in the highest part of the ceiling, as at D, in Fig. 64.

It is also recommended, that the openings for admitting cold air be about double the area of those at the ceiling. The air should not be taken from very near the ground, nor from a confined place. In designing and constructing a new building, flues might be made for the special purpose of supplying the interior with fresh air. Each flue might open in the cornice, pass down between the piers, and under the flooring of the church or other building, and terminate in apertures which would be covered with gratings. By disposing some of these flues on each side of the church, they would act with the wind in any direction. These exterior openings should, however, be covered with a grating, to prevent birds from building in them, and thus stopping them up. The accompanying sketch (Fig. 65), from a design by Mr. Garbett will shew at a glance the arrangements required for the proper

Fig 65.



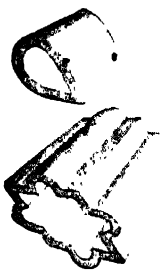
ventilation of a church; but before the desirable objects of properly warming and ventilating churches and other public buildings are fully attained, it will be necessary for architects to combine a profound knowledge of their art, with a good acquaintance with chemical and physical science.

In some of the old buildings, which still excite the admiration of persons of cultivated taste, by the beauty of their arrangements and architectural details, we sometimes meet with special provision for ventilation, arranged on the truest principles. Thus, in the "Hall of the Baths" in the Alhambra, at Granada, the roof is perforated with ventilating

Fig 66.

openings, and is not only of the best possible form for the purpose of ventilation, but the openings themselves are of the best possible shape, being wider at the lower extremity than at the upper; and in order that these openings may present the least possible amount of friction to the outgoing air, they are provided with short tubes of baked earth, covered with a green vitreous glazing. This beautiful roof is shewn in Fig. 66, and two of the elegant ventilating tubes are shewn separately on a larger scale in Fig. 67.

Fig. 67.



Such are the methods by which churches and other public buildings may be spontaneously ventilated. In the rooms of private houses, the ventilation must also be spontaneous, for if the slightest trouble be entailed on the inmates, even to the opening of a window, it will be neglected. The means for ventilation must be cheap, easily procurable, always in place, self-acting, not liable to get out of order, requiring no adjustment, no care whatever on the part of the inmates. It would seem impossible, at first view, to contrive anything at all likely to answer these conditions, and yet the thing has been done in the most perfect manner by that truly patriotic individual, Dr Arnott, so well known for his water-bed, his stove, and other inventions, which he has freely presented to the public, without seeking or desiring any emolument to himself.

In the autumn of 1849, when the cholera was raging in London and in the towns of the United Kingdom, the Board of Health recommended, in one of their notifications published in the *London Gazette*, that in every badly ventilated dwelling "considerable and immediate relief may be given by a plan suggested by Dr. Arnott, of taking a brick out of the wall near the ceiling of the room, so as to open a direct communication between the room and the chimney Any occasional temporary inconvenience of down-draught will be more than compensated by the beneficial results of this simple ventilating process."

A few days after this authoritative recommendation of this contrivance, and in consequence of numerous applications for further information on the subject, Dr. Arnott addressed a letter to the *Times* newspaper, dated 22nd September, 1849. This admirable letter is so interesting and so pertinent to the subject of this little *Rudimentary Treatise*, that we venture to transfer nearly the whole of it to our pages :—

"I assume," says Dr. Arnott, "that most of your readers

already understand, or will now learn, that the air which we breathe, and which is used to stuff air-pillows, consists of material elements as much as the water which we drink or the food which we eat,—indeed, consists altogether of oxygen and nitrogen; the first of which forms also seven-eighths by weight of the substance of water, and the other nearly one-fifth by weight of the substance of flesh; and that there is surrounding our globe, to a depth of about fifty miles, a light fluid ocean of such air, called the atmosphere, into which, near the surface of the earth, certain impurities are always rising from the functions of animal and vegetable life, and the decomposition of substances in putrefaction, combustion, &c., just as into the sea and great rivers some impurities are always entering from the sewers—all which impurities, however, are quickly so diluted or dissipated in the great masses, as to become absolutely imperceptible, and eventually, by the admirable processes of nature, are decomposed and changed, so that the great oceans of air and water retain ever their state of perfection. I assume further, that your readers know that fresh air for breathing is the most immediately urgent of the essentials to life, as proved by the instant death of any one totally deprived of it through drowning or strangulation; and by the slower death of men compelled to breathe over again the same small quantity of air, as when lately seventy-three passengers were suffocated in an Irish steam-boat, of which the hold was shut up for an hour by closely covered hatches; and by the still slower death, accompanied generally by some induced form of chronic disease, of persons condemned to breathe habitually impure air, like the dwellers in crowded ill-ventilated rooms and foul neighbourhoods; and, lastly, as proved by the fact, that pestilence or infectious diseases are engendered or propagated almost only where impurities in the air are known to abound, and particularly where the poison of the human breath and other emanations from living bodies are allowed to mingle in considerable quantity—as instanced in the gaol and ship fevers, which so lately, as in the days of the

philanthropist Howard, carried off a large proportion of those who entered gaols and ships; and, as instanced in that fearful disease, which, at the Black Assizes at Oxford, in July, 1577, spread from the prisoners to the Court, and within two days had killed the judge, the sheriff, several justices of the peace, most of the jury, and a great mass of the audience, and which afterwards spread among the people of the town. This was a fever which did its work as quickly as the cholera does now.

"Assuming that these points are tolerably understood. I shall proceed to shew, that from faults in the construction and management of our houses, many persons are unconsciously doing, in regard to the air they breathe, nearly as fishes would be doing in regard to the water they breathe, if, instead of the pure element of the vast rivers or boundless sea streaming past them, they shut themselves up in holes near the shores filled with water defiled by their own bodies, and from other foul sources. And I shall have to shew, that the spread of cholera in this country has been much influenced by the gross oversights referred to.

"All the valued reports and published opinions on cholera go far to prove, that in this climate, at least, any foreign morbific agent or influence which produces it, comes comparatively harmless to persons of vigorous health, and to those who are living in favourable circumstances; but that if it find persons with the vital powers much depressed or disturbed from any cause, and even for a short time, as happens from intemperance, from improper food or drink, from great fatigue or anxiety, but, above all, from want of fresh air, and, consequently, from breathing that which is foul, it readily overcomes them. It would seem as if the peculiar morbid agent could as little, by itself, produce the fatal disease, as one of the two elements concerned in a common gas explosion, namely, the coal gas and the atmospheric air, can alone produce the explosion. The great unanimity among writers and speakers on the subject, in regarding foul atmosphere as the

chief vehicle or favourer, if not a chief efficient cause of the pestilence, is seen in the fact, of how familiar to the common ear have lately become the words and phrases "malaria, filth crowded dwellings, crowded neighbourhoods, close rooms, faulty sewers, drains, and cesspools, or total want of these. effluvia of graveyards," &c., all of which are merely so many names for foul air, and for sources from which it may arise. Singularly, however, little attention has yet been given from authority to the chief source of poisonous air and to means of ventilation by which all kinds of foul air may certainly be removed.

"A system of draining and cleansing, water-supply and flushing, for instance, to the obtainment of which, chiefly, the Board of Health has hitherto devoted its attention, can, however good, influence only that quantity and kind of aerial impurity which arises from retained solid or liquid filth within or about a house, but it leaves absolutely untouched the other and really more important kind, which, in known quantity, is never absent where men are breathing, namely, the filth and poison of the human breath. This latter kind evidently plays the most important part in all cases of a crowd, and, therefore, such catastrophes as that of the Tooting school, with 1,100 children, of whom nearly 300 were seized by cholera, of the House of Refuge for the Destitute, and of the two great crowded lunatic asylums here, where the disease made similar havoc,—for places so public as these, and visited daily by numerous strangers, could not be allowed to remain visibly impure with solid and liquid filth, like the Rookery of St. Giles's, and other such localities. Now, good ventilation, which, although few persons comparatively are as yet aware of the fact, is easily to be had, not only entirely dissipates and renders absolutely inert the breath-poison of inmates, however numerous, and even of fever patients; but in doing this, it necessarily at the same time carries away at once all the first-named kinds of poison, arising from bad drains, or want of drains, and thus acts as a most important substitute for good

draining, until there be time to plan, and safe opportunity to establish such. It is further to be noted, that it is chiefly when the poison of drains, &c., is caught and retained under cover, and is there mixed with the breath, that it becomes very active, for scavengers, nightmen, and gravediggers, who work in the open air, are not often assailed with disease ; and in foul neighbourhoods, persons like butchers, who live in open shops, or policemen, who walk generally in the open streets, or in Paris, the people who manufacture a great part of the town filth into portable manure, suffer very little.

"To illustrate the efficacy of ventilation or dilution with fresh air, in rendering quite harmless any aerial poison, I may adduce the explanation given in a report of mine on fevers, furnished at the request of the Poor Law Commissioners in 1840, of the fact, that the malaria or infection of marsh fevers, such as occur in the Pontine marshes near Rome, and of all the deadly tropical fevers, affects persons almost only in the night. Yet the malaria or poison from decomposing organic matters which causes these fevers, is formed during the day under the influence of the hot sun still more abundantly than during the colder night ; but in the day, the direct beams of the sun warm the surface of the earth so intensely, that any air touching that surface is similarly heated, and rises away like a fire balloon, carrying up with it, of course, and much diluting, all poisonous malaria formed there. During the night, on the contrary, the surface of the earth no longer receiving the sun's rays, soon radiates away its heat, so that a thermometer lying on the ground is found to be several degrees colder than one hanging in the air a few feet above. The poison formed near the ground, therefore, at night, instead of being heated and lifted, and quickly dissipated, as during the day, is rendered cold and comparatively dense, and lies on the earth a concentrated mass, which it may be death to inspire. Hence, the value in such situations of sleeping apartments near the top of a house, or of apartments below, which shut out the night air, and are large enough to contain a sufficient

supply of the purer day air for the persons using them at night, and of mechanical means of taking down pure air from above the house to be a supply during the night. At a certain height above the surface of the earth, the atmosphere being nearly of equal purity all the earth over, a man rising in a balloon, or obtaining air for his house, from a certain elevation might be considered to have changed his country, any peculiarity of the atmosphere below, owing to the great dilution effected before it reached the height, becoming absolutely insensible.

"Now, in regard to the dilution of aerial poisons in houses by ventilation, I have to explain, that every chimney in a house is what is called a sucking or drawing air-pump, of a certain force, and can easily be rendered a valuable ventilating pump. A chimney is a pump—first, by reason of the suction or approach to a vacuum made at the open top of any tube across which the wind blows directly; and, secondly, because the flue is usually occupied, even when there is no fire, by air somewhat warmer than the external air, and has, therefore, even in a calm day, what is called a chimney draught proportioned to the difference. In England, therefore, of old, when the chimney breast was always made higher than the heads of persons sitting or sleeping in rooms, a room with an open chimney was tolerably well ventilated in the lower part, where the inmates breathed. The modern fashion, however, of very low grates and low chimney openings, has changed the case completely, for such openings can draw air only from the bottom of the rooms, where generally the coolest, the last entered, and therefore the purest air, is found, while the hotter air of the breath, of lights, of warm food, and often of subterranean drains, &c., rises and stagnates near the ceilings, and gradually corrupts there. Such heated, impure air, no more tends downwards again to escape or dive under the chimney-piece, than oil in an inverted bottle immersed in water will dive down through the water to escape by the bottle's mouth; and such a bottle or other vessel containing oil, and so placed in water

with its open mouth downwards, even if left in a running stream, would retain the oil for any length of time. If, however, an opening be made into a chimney flue through the wall near the ceiling of the room, then will all the hot impure air of the room as certainly pass away by that opening, as oil from the inverted bottle would instantly all escape upwards through a small opening made near the elevated bottom of the bottle. A top window-sash, lowered a little, instead of serving, as many people believe it does, like such an opening into the chimney flue, becomes generally, in obedience to the chimney draught, merely an inlet of cold air, which first falls as a cascade to the floor, and then glides towards the chimney, and gradually passes away by this, leaving the hotter impure air of the room nearly untouched.

"For years past, I have recommended the adoption of such ventilating chimney openings as above described, and I devised a balanced metallic valve, to prevent, during the use of fires, the escape of smoke to the room. The advantages of these openings and valves were soon so manifest, that the referees appointed under the Building Act added a clause to their bill allowing the introduction of the valves, and directing how they were to be placed, and they are now in very extensive use. A good illustration of the subject was afforded in St. James's parish, where some quarters are densely inhabited by the families of Irish labourers. These localities formerly sent an enormous number of sick to the neighbouring dispensary. Mr. Toynbee, the able medical chief of that dispensary, came to consult me respecting the ventilation of such places, and, on my recommendation, had openings made into the chimney flues of the rooms near the ceilings, by removing a single brick, and placing there a piece of wire gauze, with a light curtain flap hanging against the inside, to prevent the issue of smoke in gusty weather. The decided effect produced at once on the feelings of the inmates was so remarkable, that there was an extensive demand for the new appliance, and, as a consequence of its adoption, Mr. Toynbee had soon to report,

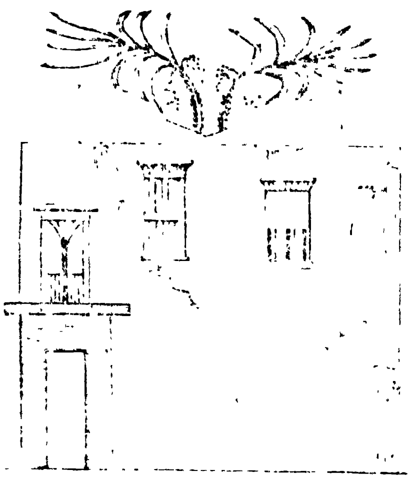
in evidence given before the Health of Towns Commission, and in other published documents, both an extraordinary reduction of the number of sick applying for relief, and of the severity of diseases occurring.* Wide experience elsewhere has since obtained similar results. Most of the hospitals and poor-houses in the kingdom now have these chimney-valves. and most of the medical men and others who have published of late on sanitary matters, have strongly commended them. Had the present Board of Health possessed the power, and deemed the means expedient, the chimney openings might, as a prevention of cholera, almost in one day, and at the expense of about a shilling for a poor man's room, have been established over the whole kingdom.

"Mr. Simpson, the registrar of deaths for St. Giles's parish, an experienced practitioner, whose judgment I value much. related to me lately, that he had been called to visit a house in one of the crowded courts, to register the death of an inmate from cholera. He found five other persons living in the room, which was most close and offensive. He advised the immediate removal of all to other lodgings. A second died before the removal took place, and soon after in the poor-house and elsewhere, three others died who had breathed the foul air of that room. Mr. Simpson expressed to me his belief that if there had been the opening described above into the chimney near the ceiling, this horrid history would not have been to tell. I believe so too, and I believe that there have been in London lately very many similar cases."

* We are truly thankful to be able to state, that in two parishes in London - St. George's and St. James's—a society has been established for the purpose of supplying the sick poor with clothing, food, and *means for ventilating their apartments*. The Honorary Secretary to this society is Joseph Toynbee, Esq., 60, King Street, Golden Square, who has volunteered to give the necessary information to any District Visiting Society desirous of extending their usefulness by ventilating the dwellings of the poor. We trust that Mr. Toynbee's benevolence will be rewarded by extensive success.

Among other modes of spontaneous ventilation, may be mentioned the *mulquf*, or wind conductor, of the ancient Egyptians, and still in use in modern Egypt. It was erected at the top of the house, as in Fig. 68, and consisted of a frame covered or enclosed on all sides, except at the mouths, which were open in the direction of the prevailing winds. The roof of the mulguf sloped down from each open end to the centre, where a partition divided it, and deflected the wind down into the apartments below. Mr. Wilkinson, in his work on Egypt, gives a view of part of Cairo, shewing the mulgufs on the houses of the modern Egyptians. The ancient mulgufs were double, as shewn in the figure, but the modern ones are single, and the opening is in the direction of the prevailing north-west wind. They consist of strong frame-work, to which several planks of wood are nailed, according to the breadth and length proposed; and, if required of cheaper materials, reeds or mats, covered with stucco, are used instead of planks.

Fig. 68.



This contrivance acts on a similar principle to the *wind-sail* used on board ships, which consists of a sail spread out to the wind: from the lower part proceeds a cylinder of canvas distended by hoops, which may be carried down through the hatches, to any deck or hold where fresh air is required. Its action depends on the force of the wind, and the mode of arranging it: it is of no use in calm weather, when ventilation is often most needed: and it is equally unavailable in stormy weather,

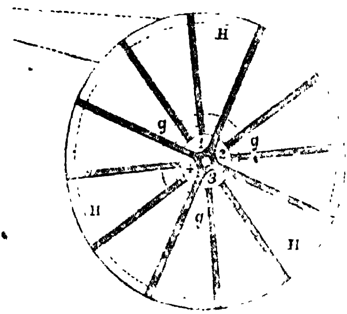
when the hatches are battened down, and the men crowded below. Indeed, unless some contrivance could be made for getting rid of the vitiated air by other openings, the supply of fresh air by the wind-sail must always be partial and defective.

The next class of mechanical contrivances for ventilation, is that in which the aid of an attendant is required, either to maintain the ventilating machine in motion, or to superintend the mechanical power that does so. The simplest of these contrivances is the *fan*, which has been used from time immemorial, especially in warm climates, where it is often made of an enormous size, and being wielded by an attendant with the dexterity acquired by long practice, its effect is very powerful in giving motion to the air, and producing the sensation of coolness, by bringing a larger supply to the person, and abstracting the heat by its motion. The *punkah*, as commonly used in India, is nothing more than a gigantic fan, suspended in the centre of the apartment, above a bed or table. Attached to one side is a line, which passes out of the apartment through the wall to an attendant on the outside, who thus gives motion to the large extended surface within, and thus prevents the air from stagnating. Some years ago, a steam-engine was sent from England to move the punkahs in the palace of the Nabob of Oude. A machine, called the *zephyr*, was proposed some years ago by Mr. Dobson, for giving motion to the air of a room. Two sails or punkahs, crossing each other at right angles, were mounted on a frame, and a rotatory motion was given thereto, by suspending it from a case containing a mechanism like that of a bottle-jack. This case was suspended by lines passing over pullies in the ceiling, and balanced by weights, so that the sails could be made to play at any elevation. In all these contrivances, motion is given to the air, but the rooms containing them are not ventilated thereby; the vitiated air is whirled and whisked about, but not driven out, and its place supplied by fresh air.

This objection does not apply to the fanning-wheel or blower, now so commonly used for ventilating factories and other

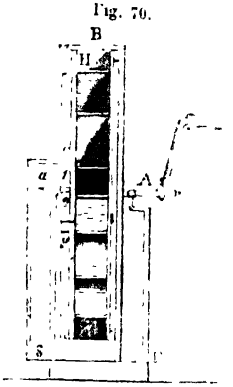
places where a steam-engine is constantly at work, to supply the required moving power. The fanner was invented by Dr. Desaguliers, in 1734. Its object was stated to be for "changing the air of the room of sick people in a little time, either by drawing out the foul air, or forcing in fresh air, or doing both successively, without opening doors or windows." This, it was supposed, would be of very great use in all hospitals and prisons, and would also serve to convey air into a distant room, "nay, to perfume it occasionally." The wheel was 7 feet in diameter, and 1 foot wide, and had twelve radii

Fig. 69



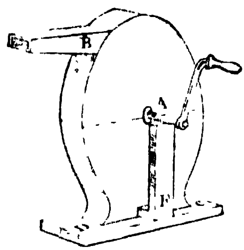
or partitions, (Fig. 69), approaching within 9 inches of the axis, leaving a circular opening 1, 2, 3, 4, 18 inches in diameter. This wheel was enclosed in a concentric case, (Fig. 71), furnished with a blowing pipe, B, on the upper part and a suction pipe, S (Fig. 70), communicating at *a*, with the central opening

Fig. 70.



in the wheel, which was turned by a handle, attached to the axis, A, which passed through the case, and rested on a standard, E. The fanner was made so as to revolve easily, but as closely to the concentric casing as possible, without any communication with the air, except through the suction and blowing pipes. To ensure this, a ring of blanketting was fixed within the case, *g g*, and a similar ring at H H, so that the edges of the vanes being in contact therewith, the air would have no other escape than by the blowing pipe, B. By the revolution of the wheel, the air within the case was rapidly impelled by centrifugal force to the cir-

Fig. 71.



cumference, where it was condensed, whirled round, and forced out, in a powerful current, through the opening of the blowing pipe, B, while the partial vacuum thus formed set a current of air in motion towards the centre, which current entering at S, and passing up into *a*, was distributed between the vanes, and, driven to the circumference, passed out in a powerful continuous blast at B. The suction-pipe, S, could be made to communicate with the external air by means of a pipe, or with a space containing heated air, and the blowing pipe could be connected with a room which could thus be filled with cool fresh air, or with warmed air, the quantity being regulated by the speed of the wheel. If foul air had to be drawn out, the suction-pipe was connected with the space containing it, and the blowing-pipe with the external air.

In the year 1736, a wheel of this description was erected over the ceiling of the House of Commons, for the purpose of drawing out the vitiated air, in the manner just described, a man being kept constantly at work, during the sitting of the house, to turn the wheel. It was stated, that this wheel was "able to suck out the foul air, or throw in fresh, or do both at once, according as the Speaker is pleased to command it, whose order the ventilator waits to receive every day of the session." This apparatus continued to be used for ventilating the House, until the year 1791, when the chief clerk of the House, Mr. Holland, proposed its removal from the room over his own private apartments, to the centre of the roof immediately over the House, as being a more advantageous position. This was accordingly done, and continued in operation until 1817, when a similar contrivance was recommended for the ventilation of the House of Lords. It was not, however, erected, for in 1820, the whole business of warming and ventilating both Houses was entrusted to the Marquis

of Chabannes, whose plan will be noticed in the next chapter.

But to return to Dr. Desaguliers. About the time when he was engaged in ventilating the House of Commons, the attention of Government was directed to the want of ventilation in our ships, in consequence of the bad health of the troops that were embarked at Spithead to proceed on an expedition against the Spaniards. Numbers were relanded, and sent to the hospital, and the ships are said to have "stunk to such a degree, that they infected one another." "The Lords of the Admiralty applied to Dr. Desaguliers, to shew them the model of his centrifugal wheel and air-pipes; and after the exhibition, some of them went to see the operation of the wheel fixed over the House of Commons. Sir Jacob Ackworth, the Surveyor of the Navy, attended them, and seemed to approve of the machine as much as they did; and the Doctor was ordered to make a blowing wheel, with its pipes, to be tried on board the *Kinsale* at Woolwich, but less than that at the House of Commons, that it might not take up too much room in the ship." Accordingly, the Doctor attended with a small wheel, but Sir Jacob did not condescend to be present. The machine answered admirably: a quantity of pitch and other substances was burnt in the carpenter's room, and the smoke arising therefrom was drawn above deck by a few turns of the wheel. On reversing the valves, air was forced between decks with great energy. Every one present was delighted with the action of this ventilator, and Sir Jacob, hearing of its success, appointed another day for a repetition of the experiment, but requested the Doctor not to attend himself, but to send his carpenter with the apparatus. The particulars of this trial are amusingly told, in a letter from the carpenter, Kembel Whattley, to Dr. Desaguliers.—"When Sir Jacob came on board, he was very complaisant to me, and asked me if I was the person that was appointed by Dr. Desaguliers to attend him, in order to try the experiment of the air machine, and I told him I was. Then said he to the men, 'hoist the wind-

sails;' and the windsails were hoisted. 'Now,' says he to me, 'we have cut two scuttle-holes at each end of the ship, and you shall see what the windsails will do; it is our old way when at sea:' and while they were hoisting the sails, I went down under deck to put the engine in order. But I had not been there long, before I was called for. So when I came up it was to see that the wind-sails that were put down would blow out a candle at one of the scuttle-holes. 'Now,' said he, 'I would have you work the engine, and see whether that will throw out so much air as our wind-sails you see do.' 'Lord! Sir,' said I, 'that, I imagine, was not the intent of the thing; it was to draw out the foul air from any part of the ship that there were tubes to convey it from. It is impossible that a thing, which is but 3 inches by 5, should throw in as much air as a thing 2 feet 6 inches diameter.' So we talked awhile, and, at last, he told me that he could not stay, but that he had thought so before, and that he was sorry that the machine would not do. 'Pray, Sir,' said I, 'let there be a great smoke made in the carpenter's store-room, and see whether the engine or your wind-sails will destroy it first.' Then he told me, that he could not possibly stay; 'but that gentleman there,' said he, pointing to a pretty lusty man that was present, 'shall be with you, and he and you may try the machine as you please; and I shall think the same of it, from his report, as if I were present.' So, Sir, it was then left to the gentleman and me to try it; and I burned pitch in the carpenter's store-room, and made a great smoke, and ordered the engine to be worked, and drew it out in less than five minutes' time. Then I turned the valves, and brought in fresh air; and, as I thought, it gave the gentleman entire satisfaction; but, however, we made as great a smoke as before, and put down the windsails, and then the smoke was driven into several parts of the ship; and that not in half the time that your engine did it in; and then it went out above deck. Sir Jacob told me afterwards, that he was sorry that it succeeded no better, but he thought it might be a very pretty thing in a house. Sir Jacob desires his humble service to you."

Dr. Desaguliers complains justly, that "not one of the Lords of the Admiralty, who talked of having many of the ventilators made for the preservation of the health of the persons then going to Jamaica, condescended to witness one experiment; and Sir Jacob, who condemned the thing, would not once be present to observe its operation. But thus ended my scheme, which, I hoped, would have been of great benefit to the public."

The great objection to this plan for ventilating ships, is the necessity of employing men to turn the wheel. The dangers arising from defective ventilation are not of that obvious character which, in many other cases, lead men at once to seek out and apply the remedy. The aerial poison is invisible, and, although chemists and educated persons, who study its nature, are aware of its insidious action in inducing disease, and undermining the health, it is difficult to persuade the multitude, whether of subordinates or of persons in authority, that pure air is as necessary to health and vigour of body, as food, and sleep, and cleanliness. On board a ship, every one has his regular routine duties, the use of which are obvious to those who command as well as to those who perform them, and they are accordingly performed with cheerfulness. But to give the common sailor, in addition to his other duties, the task of turning a wheel for the purpose of pumping out air from between decks, is not likely to be of obvious utility, either to him, or to many of his commanding officers. No system of ventilating apparatus is ever likely to be adapted to the conditions of a ship, unless it resemble the excellent system of lightning conductors, invented by Sir W. Snow Harris; it must be always in its place, ready for use, under all possible circumstances, whether wanted or not. Before Harris's conductors were introduced, every ship was furnished with a set of moveable conductors, packed up in a box, to be taken out and applied when wanted. Now the taking out and erecting of these conductors was an extra duty, a special service—and was seldom or never performed. A thunder-storm comes on, the ship had not been struck in other storms, why should it

be struck in this? and, accordingly, the conductors are left to slumber in the hold. So with any form of ventilating apparatus that gives extra trouble to officers or men; the ship's company have never been suffocated for want of air—why should they now? Hence all these new-fangled contrivances are dismissed with scorn.

Very differently circumstanced is the ventilating fan when made a permanent fixture in a factory, and the wheel is connected with the force which sets in motion the various machines of the establishment. The ventilator then fulfils all the conditions required. It is always in its place, gives no trouble, does its duty efficiently, and requires no superintendence In speaking of the ventilation of factories, Dr. Ure remarks, that the engineers of Manchester do not, like those of the metropolis, trust for a sufficient supply of fresh air into any crowded hall, to currents physically created in the atmosphere by the difference of temperature excited by chimney draughts; but the factory plan is to extract the foul air in measurable volumes, by mechanical means of the simplest and most unfailing kind, especially by eccentric fans, made to revolve with the rapidity of nearly 100 feet per second; and thereby to ensure a constant renewal of the atmosphere in any range of apartments, however large or closely crowded they may be. The effect of one of Fairbairn and Lillie's four-guinea fans upon a large factory is truly admirable; it not only sweetens the interior space immediately, but renders the ingress of bad odours from without impossible. In a weaving mill, near Manchester, where the ventilation was bad, the proprietor caused a fan apparatus to be mounted. The consequence soon became apparent in a curious manner. The work people complained that the ventilator had increased their appetites, and therefore entitled them to a corresponding increase of wages.

When such a fan, placed at one end of an apartment about 200 feet long, is in full action, it throws the air so powerfully out of it, as to create a draught at the other end of the room,

capable of keeping a weighted door six inches a-jar. When connected in the attics with a horizontal pipe, into which vertical tunnels from each room are inserted, it draws out the air so rapidly from them, as to cause a breeze from every part of the adjoining floors, thus producing an excess of ventilation in the apartments. The simple and cheap contrivance of perforated cast-iron boxes, placed on every story in communication with the fan, is the method now in use. A side and a front view of the fan are given in Figs. 72, 73, such as have

Fig. 72.

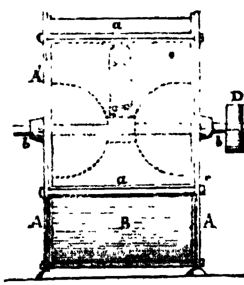
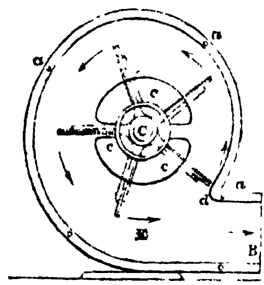


Fig. 73.



been used of late years for ventilating factories, for removing through tunnels the dust disengaged in cleaning fibrous materials, such as cotton, hemp, &c., for blowing air into forge fires, and many other similar purposes. It consists of two cast iron end plates, A A, with a central circular opening, *c c c*, from the circumference of which the outline of each plate enlarges spirally, the point nearest the centre being near *d*, and that furthest off being under E. This pair of parallel plates is connected by bolts, *a a a*, a mantle of sheet iron being previously inserted into grooves cast in the edges of the end plates, so as to enclose a cavity with an elongated outlet at B, to which a pipe is attached for carrying off the air in any direction. Within this cavity, a shaft, C, revolves in bearings, *b b*, placed centrally in the frame-plates, A A. On this shaft, a boss is wedged fast, bearing five flat arms, *c c c*, to which are rivetted five flat plates or wires of the shapes shewn between

a and *a*, in Fig. 73, having a semi-circular piece cut out of them on each side, about the size of the end opening. On one side of the shaft, C, beyond the box-bearing, the fast and loose pulleys, D, are fitted for receiving the driving band, and for turning the wings in the direction shewn by the arrow. Thus the air is driven before them out of the end orifice, B, while it enters by the side openings at *c c c*. By the centrifugal force of the revolving wings, the air is condensed towards their extremities, and makes its escape from the pressure through the orifice, B, while it is continually drawn in at the sides by its tendency to restore the equilibrium. The fans are sometimes constructed so as to have their mantles concentric with their central shafts, as in Dr. Desaguliers' fan. The improved fan (shewn in Fig. 73), is called the eccentric; the air which escapes through the outlet, B, has undergone compression during its whole progress through the spiral space with the revolving wings, and is equal in density to that compressed at their extremities by the centrifugal force. The fan, therefore, discharges considerably more air than that with a chamber concentric with its wings (as in Fig. 69), because in the concentric fan, there is considerable loss of power, on account of a large quantity of air being carried round by the leaves of the fan, instead of passing out through the discharge pipe at the circumference; but in the eccentric fan, each wing or leaf, in passing the point, *d*, acts as a valve to cut off the entrance of the uncondensed air, which would cause an eddy, and retard the proper current by the inertia of its particles. When the fan is required to draw air out of a series of independent rooms, it has its circular side openings, *c c c*, enclosed within caps, which are connected with pipes communicating with such rooms. Slide or throstle valves may be placed in the exhausting, as well as the condensing pipes, for regulating the distribution of the rarefying or blowing power.*

The fan produces its greatest effect when the extreme points

* *Philosophy of Manufactures.* London, 1835.

of its leaves move through about 80 feet per second. The mean velocity of that portion of the vanes by which the air is discharged, is about seven-eighths of the velocity of the extremities; but owing to the inertia of the air, there will be a loss in the velocity of the issuing current which will increase with the increased speed of the vanes; so that, in general, the current will be discharged with a velocity equal to about three-fourths of the velocity of the extremities. This velocity measured in feet per second multiplied by the area of the discharge pipe in square feet, will give the number of cubic feet of air discharged per second. If the effective velocity of the vanes be 70 feet per second, and the sectional area of the discharge tube be three square feet, then $70 \times 3 = 210$ cubic feet of air discharged per second or 12,600 cubic feet per minute. As a cubic foot of air weighs 527 grains, there will be about 13 cubic feet of air to a pound; therefore $\frac{210 \times 60}{13} = 969$lbs. weight of air set in motion per minute, with a velocity of 70 feet per second. The height from which a heavy body must fall in order to acquire a velocity of 70 feet per second is 76.5 feet, which multiplied by the number of pounds weight moved per minute, will give the power necessary to discharge this quantity of air at the stated velocity; and this product divided by 33,000 (the number of pounds weight that one horse will raise one foot high per minute) will give the amount of steam-power required. Therefore $\frac{76.5 \times 969}{33,000} = 2.24$ or nearly $2\frac{1}{4}$ horses power will be required to discharge the given quantity of air at the velocity stated.*

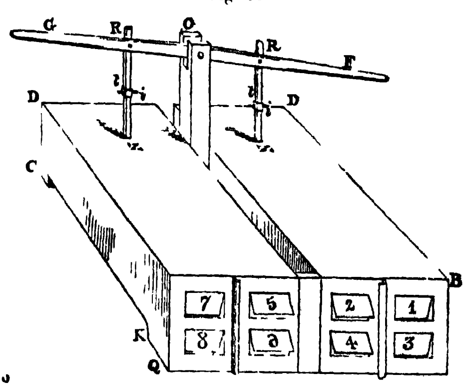
The Archimedian screw has lately been proposed as a substitute for the fan in the ventilation of buildings; but it appears to be in every respect an inferior machine. The only thing that can be said in its favour is, that it is entirely self-acting, requiring no power to set it in motion,

* Ure, *Philosophical Transactions.* Hood, *Warming and Ven-*

except the ascensive force of the vitiated air itself, which acting on the threads or spirals of the screw, causes it to revolve, and so effects the discharge. This, of course, is an advantage; but as soon as the pressure or condensation of the air between the spirals becomes equal to the friction between the air and the surface of the spirals, no further increase in the amount of discharge takes place. The screw will only discharge small quantities of air at a moderate velocity, and is, therefore, not fitted for ventilation on a large scale.

Pumps and bellows have also had their share of attention as instruments of ventilation. At the time when Dr. Desaguliers was endeavouring to get his ventilating fans introduced into the navy, Dr. Hales came forward with a rival scheme, which he termed the "Ship's lungs," and he was applied to by Government to fix his apparatus on board the *Captain*, a seventy gun ship, by way of experiment. A double ventilator of this kind is shewn in Fig. 74. It consisted of two outer cases, B D Q C, each 10 feet long, $4\frac{1}{4}$ feet wide, and 13 inches deep inside. The midrif or valve, z, (Fig, 75), was framed of wood, and fixed at one end to each case by iron hinges, and a slip of leather was nailed over the whole length of the joint to make

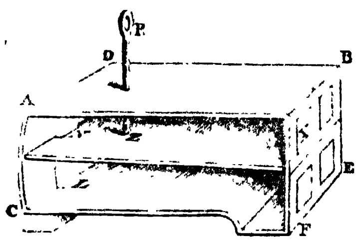
Fig 74



it air-tight. This valve moved easily up and down as near the surface of each case as possible. Iron rods, R R, were fixed

about six inches from the moveable end of the midrif at N, and were furnished with joints made like two links in a chain, to allow them to preserve a perpendicular position in the motion caused by the rising and falling of the midrifs. The upper ends of these rods were attached to a lever, G F, 12 feet long, moving on a pivot at O, and capable of being worked by two men. The valves marked 1 to 8, each 22 inches long, 6 inches deep, and suspended by copper hinges, were an inch broader and longer than the openings; and their borders, as well as the corresponding borders of the valve openings, were lined with list or woollen cloth, to deaden their noise when falling. A box with a large aperture, covered the emission valves, from which the air was conveyed by a pipe into the part of the ship that was to be ventilated. Thus, it will be seen, that the construction of this machine closely resembles that of the common bellows. The air enters by those valves which are hinged to open inwards, and is emitted at each rise and fall of the midrif through the valves which are hung so as to open outwards into the covering-box, whence it is conveyed through a tube to the parts of the ship requiring ventilation.

Fig. 75.



Dr. Hales calculated that his machine would expel a tun of air at each stroke, or six tuns per minute; and that the air issued from the aperture with a velocity of twenty-five miles an hour. This estimate is far too high, and the machine itself is far inferior to that of his amiable rival, Dr. Desaguliers; indeed, the use of the rotatory fan at the present day, and the total practical oblivion of the "Ship's lungs," is a sufficient commentary on the respective merits of the two inventions.

In the experiment in the *Captain*, Sir Jacob Ackworth

condescended to be present, and appears to have behaved to Dr. Hales with civility. It is very probable, that on this occasion, the objection urged against this machine was, that it was not self-acting, but required too constant attention of the seamen to be of any use, for the Doctor, in his treatise, endeavours to combat such objections in the following terms:—"As to the labour and difficulty of working these ventilators, how frivolous and groundless is it when the matter is rightly considered; for as they are chiefly wanted where there is a great number of men, so the labour of it, equally divided among them, is very inconsiderable; for if two men can hold to work them for a quarter of an hour, four men, by changing hands, *spell* and *spell*, as they term it, may well work for an hour. And suppose there be 500 or 480 men in a ship, and every one takes his share of the work, then, once in five days, it will come to every man's turn to work at it for half an hour. And suppose there be in a transport or *Guinea* slave ship 200 men, as there is often about that number, then it will come to every man's turn to work the ventilators for half an hour once in forty-eight hours; but here, as the ventilators will be less than the above described ventilators, so will the labour of working them be also less. This, supposing it necessary to do it incessantly night and day, which need not be in a man-of-war when the port-holes can be opened, and there is any degree of wind; which, suppose it be half the time of the crew's being on ship-board, then it will come to each man's turn but once in ten days. This calculation is made on a supposition, that every individual takes his turn at the ventilator; but let us allow an abatement of one-fifth for officers, sick, &c., then will the work be no more than half an hour to each man in eight days. But suppose it were to be incessant, can half an hour in five days be thought so hard and great a degree of labour as to render the working of the ventilators an impracticable thing? Is not the benefit proposed thereby, viz., the saving yearly of the lives of thousands, a sufficient reward for so small a pittance of labour? Shall it be said of the brave and un-

daunted sailor, that rather than pull his hand out of his bosom, and work for an hour once in ten days, he will choose to lie down and suffer his brave manly spirit to be suffocated in a frowsy stench—a stench that has destroyed the lives of millions of the stoutest and bravest, for the lamp of life is sooner thereby quenched than many are aware of."*

All this argument is perfectly sound, and it must be admitted, that each sailor ought to "work for an hour once in ten days," in order to keep the ship well ventilated. It must also be admitted, that under the old system of lightning conductors, the approach of every storm ought to have been a sufficient warning to cause the erection of these safe-guards, in case the ship should be struck. There are many things in life which men ought to do, and much learned and scientific eloquence is repeatedly urged in favour of their doing them; but, as indolence, indifference, and ignorance, are not easily moved to exertion, the benefit must, if possible, be conferred without occasioning thought, trouble, or exertion to those who are to share in its advantages.

Such a contrivance was introduced into English vessels of war, at the very time when the respective merits of Dr. Desaguliers and Dr. Hales' schemes were being discussed. This was Mr. Sutton's air tubes, which will be noticed in the next chapter. These were perfectly successful; but as the plan was made the subject of a patent, and some objection

* The title of this book is curious, and it promises more than the machines described in it were calculated to perform. It is as follows:—"A description of ventilators, whereby great quantities of fresh air may with ease be conveyed into mines, gaols, hospitals, workhouses, and ships, in exchange for their noxious air. An account also of their great usefulness in many other respects; as in preserving all sorts of grain dry and sweet, and free from being destroyed by weevils both in granaries and ships, and in preserving many other sorts of goods; as also in drying corn, malt, hops, gunpowder, &c., and for many other useful purposes. Which was read before the Royal Society, in May, 1741. By Stephen Hales, D.D., F.R.S., Rector of Farringdon, Hampshire, and Minister of Teddington, Middlesex. London, 1743."

had been made to the paying for the use of it on board each ship, the scheme seems to have died with the inventor, for we find the complaints of the defective ventilation of ships to be as numerous as ever, and no further improvement appears to have been made until about the year 1785, when wooden pipes, about nine inches square, were introduced (for which brass tubes were afterwards substituted), running from between decks along the side of the ship, and opening into the air over the gunwale of the forecastle.* The importance of this contrivance will be seen, when it is considered, that in frigates the sleeping-places of the men are excluded from direct communication with the external air; and that a number of human beings crowded together in hammocks for hours together, in a small dark confined space, must be highly injurious to health. Attempts had been made to remedy this by small scuttles cut in the the sides; but this was frequently objected to, as weakening or endangering the ship.

One of the most recent additions to our ventilating apparatus is Dr. Chowne's patent air-siphon, which acts on a similar principle to that of the smoke consuming stoves, described at page 68, (Fig. 16), and also at pages 105, 107, (Figs. 32 and 33.) Fig. 32 was spoken of by Dr. Franklin, "as a kind of inverted siphon; and as the greater weight of water in the longer leg of a common siphon, in descending, is accompanied by an ascent of the same fluid in the shorter, so in this inverted siphon, the greater quantity of levity of air in the longer leg in rising, is accompanied by the descent of air in the shorter." In the specification of his patent, Dr. Chowne states his invention to consist in the application of a principle which he has found to prevail in the atmosphere, of moving up the longer leg of an inverted siphon, and of entering and descending in the shorter leg, and this without the

* This contrivance was first pointed out by Dr. Gilbert Blane, in his work *On the Diseases Incident to Seamen*. London, 1785, and the idea was suggested to him from a similar contrivance in *La Nymphe*, a French frigate.

necessity for the application of artificial heat to the longer leg. "I have found that if a bent tube or hollow passage be fixed with the legs upwards, the legs being of unequal lengths, whether it be in the open air or with the shorter leg communicating with a room or other place, that the air circulates up the longer leg, and it enters and moves down the shorter leg, and that this action is not prevented by making the shorter leg hot whilst the longer leg remains cold, and no artificial heat is necessary to the longer leg of the air-siphon to cause this action to take place; thus, is the direction of the action of air in a siphon the reverse of that which takes place in a siphon, or like bent passage or tube, when used for water and other liquid, wherein the water or other liquid enters and rises up in the shorter leg, and descends or moves down into the longer leg. And my invention consists of applying this principle when ventilating rooms or apartments, such as those of a house or ship, or other building or place."

He then goes on to describe the invention as applied to the rooms of a house where there are chimneys opening into such rooms, and says, in these cases, "I employ the chimney as the longer leg of the air-siphon, which I arrange in order to ventilate a room, and I am enabled to use the chimney whether for the time being there is or is not a fire lighted in the fire-place of the room; but I prefer, when there is no lighted fire, that the fire-place should be closed either by a register stove being shut, if one be used, or, if not, by a close chimney-board, or by other convenient means, and I form a passage or channel either when constructing the building, or by cutting away, if not previously constructed, or I otherwise form such channel or passage, or more than one, from the upper part of the room, or near the ceiling of the room, and cause it to descend and to enter the chimney at a point above the top of the fire-place, when it is an open fire-place, and it may be lower down when closed; and in order that the whole of the upper part of the room may be in communication with such descending passage or channel leading to the chimney, I form a hollow

cornice sufficiently open to allow of the atmosphere at or near the upper part of the room to flow into the same, and owing to the atmospheric siphon which will thus be formed, there will be a constant flow of the air in a direction from the upper part of the room down the descending channel or passage, which will represent the shorter leg, and thence into the chimney, and away up the chimney, which will constitute the longer leg of the air-siphon."

When fixed gas-burners or lamps are used, then he prefers that a tube or hollow passage should be conducted down to form the shorter leg of the air-siphon, in any convenient direction, and be caused to enter the chimney as before described, or such channel or passage may be of metal or other material projecting from the walls of the buildings, or it may be down pillars or channels independent of the walls, where the architecture or ornamental portion of the walls or other parts will admit of it; and, so far from its being necessary that there should be any bell over the chimney of a gas-burner or other lamp, the patentee has found, that having close to the top of the glass chimney a *lateral* tube, opening into the shorter leg of the siphon, is by far the most effectual way of getting rid of the heated air from the lights: the products, in place of rising up and becoming diffused in the room, pass rapidly through the lateral tube into the shorter leg of the siphon.

Dr. Chowne states, that he has at all times found an upward current in the longer leg of his siphon, whether that longer leg consisted of the shaft of a chimney or a pipe run up against the outside of his house, and bent at the bottom, so as to form the shorter leg. This result certainly does not agree with experience; for, unless means exist for establishing an upward current by the application of heat to some part of the inverted siphon, we must suppose that a descending current is as likely to exist in the long leg of the siphon as an ascending one. In summer, there is a constant interchange taking place between the air of our apartments and the external air, by means of the chimney flues, which afford the readiest

method of intercommunication. Whether the current in the flues be ascending or descending, depends chiefly upon differences of temperature within and without; but, as the brick-work of chimneys often gets heated by the vicinity of the kitchen flue, or even by the sun shining upon it during the day, an ascending current is more likely to be sustained than a descending one, since brick-work will retain its heat for many hours. When, according to Dr. Chowne's arrangement, the chimney opening is stopped up with the exception of an aperture for receiving the short leg of the siphon, the following phenomena are likely to take place. If, during the day, the room be occupied, and its temperature be raised by the respiration of the occupants, and the doors and windows be kept tolerably close, there will be an upward current in the chimney which will draw upon the air of the room, and ventilation will go on. As evening advances, and lamps and candles are introduced, the doors and windows still being closed, the increased elasticity of the air of the room arising from these sources of heat would be likely to counteract any tendency of the air to descend the chimney or long leg of the siphon. In fact, the system of ascending currents which has been perfectly maintained during the day, is strengthened and supported by night, in consequence of the increased elastic force of the air of the room maintaining and assisting the ascending current; and hence, ventilation will be maintained by night as well as by day; and even, when the lights are all extinguished and the occupants have retired, the temperature of the room being greater than that of the outer air, ventilation would still go on up the chimney, although in a more feeble manner, provided the doors be kept closed. If the doors were left open, the room would gradually cool down, and the ventilating system might possibly be overturned by a descending current. In fact, this system of ventilation seems closely to resemble the cases mentioned at pages 87, 88, where two fires are burning in one large room; if one burn well and the other badly, and the doors and windows be tight, so that there is not a

sufficient supply of air in the room to support combustion, the briskly burning fire will draw upon the chimney of the badly burning fire, and the air will be drawn down its shaft to make up the supply. Or a strong kitchen fire badly supplied with air, will draw upon the other chimneys of the house whenever a door is left open. In Dr. Chowne's arrangement, when once an upward current is established, the long leg of his siphon is in the condition of a briskly burning fire, and the room or space to be ventilated is in the condition of the badly burning fire, whose shaft is drawn upon to supply its more vigorous neighbour.*

The statement, that there is always an ascending current in the long limb of the siphon, except occasionally during gusts of wind, we should be disposed to doubt. If an inverted siphon of large bore be erected in the middle of an open plain, far from any artificial disturbing causes, and the long limb be from 20 to 50 feet high, and the short limb only a few feet high, there is no reason why there should be any current at all within the tube, so long as the enclosed air were of the same temperature as that on the outside. But if the sun shone upon the tube, an ascending current would be generated; if a very cold wind blew upon it, or if after rain the evaporation from the surface were strong, and by such means the tube were greatly reduced in temperature, a descending current would probably be established.

The whole system, however, is ingenious, and deserves attention. The writer had an opportunity of seeing this ventilator in action at one of the evening meetings of the Pharmaceutical Society, on the 15th of May last, and it seemed to be very efficient. A number of gas-burners arranged round the short leg of the siphon, discharged into it

* At the time of revising this sheet, the writer is sitting in a study in which lamps have been burning for some hours. There is no fire in the study nor in an adjoining dining room, which is separated from it by a wall, and yet the chimney of the study draws upon the chimney of the dining-room, for there is a strong downward current in the latter, and an ascending current in the former.

all the products of combustion so completely, that the hand could be held immediately over the glass chimney of any one of the burners without the slightest inconvenience, and a piece of white writing paper, permanently fixed an inch or two above each chimney, was neither blackened nor scorched.

Many years ago, Tredgold recommended a siphon for withdrawing the foul air from the interior of apartments. "If an inverted siphon," he says, "be placed with one leg in the chimney, so near to the fire, that the air in that leg will be warmer than the air in the other leg, motion will take place; for the air will ascend in the warm leg and go up the chimney, and a descending current in the cool leg will take the air from the room. To render the application of this principle successful, the mouth of the tube should be at the ceiling of the apartment; the lowest part of the curve should be, as much as convenient, below the point where the heat is applied; and the aperture through which the air flows into the chimney, should be formed so that the soot may not fall down the tube: also, the mouth should have a register to close it, or regulate the ventilation."

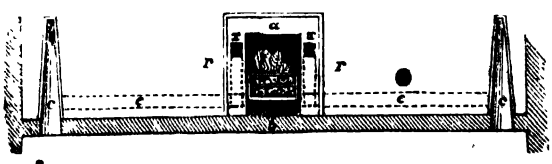
CHAPTER II.

ON THE VENTILATION OF BUILDINGS, SHIPS, MINES, ETC., BY MEANS OF ARTIFICIAL HEAT.

AMONG the special contrivances for producing ventilation, combustion occupies a prominent part. By applying heat to the air in the upper part of the ventilating tube, the air of the place requiring ventilation is drawn upwards with increased rapidity, and fresh air rushes in with a proportional increase of rapidity to supply its place. This method of producing artificial ventilation seems to have been first described by Rodolphus Agricola, in the sixteenth century. In his book, *De re Metallica,* he speaks of the method of drawing the foul

air out of a mine, by suspending a large fire in the middle of the shaft, a method which has been practised in mines ever since his time. This method does not appear to have been adopted in the ventilation of crowded rooms, until the year 1723, when Dr. Desaguliers was requested to endeavour to improve the arrangements made some years before by Sir Christopher Wren, for the ventilation of the House of Commons. Wren's plan was as follows:—a large square hole was made in the ceiling at each corner of the house, and over each hole, in the room above, was erected a hollow truncated pyramid, six or eight feet high, constructed so as to be closed at pleasure. The vitiated air of the house escaped by these holes when the temperature was sufficient for the purpose; but it often happened that the colder and denser air of the upper room not only stopped the ascending current, but poured down in cataracts upon the members below. This defective arrangement was remedied by Dr. Desaguliers, in an ingenious manner. He constructed a closet at each end of the upper room between the pyramids, and conducted a trunk from the pyramids to the square iron cavities that surrounded a fire-grate in each closet. When, therefore, the fires were lighted in these grates, air ascended from the house, through the heated cavities, into the closets, and was thence discharged up the chimneys. This arrangement is represented in Fig. 76, in which *c c* are the pyramids at one extremity of

Fig. 76.



the room, opening from the ceilings of the house; *e e*, two pipes leading from them to the fire-grate, *a b*. The heat of the fire, rarefying the air in the iron cavities, *x x*, a current would be produced in *e e*, and the air from the pyramids would flow out at *x x* into the closets, and thence into the chimney.

The principle of this arrangement is perfectly sound, and there is no doubt that it would have answered the purpose required, if it had had fair play. The cause of its failure is curious. Mrs. Smith, the housekeeper of the House of Commons, feeling herself aggrieved at being disturbed in the possession of "her rooms," discovered an easy method of persuading the honourable members that the philosopher's plan had failed. She carried her point, "by not having the fires lighted until the house had sat some time, and was very hot; for then the air in the closets that had not been heated went down into the house, to an air rarer and less resisting, whereby the house became hotter, instead of being cooled. But when the fire had been lighted before the meeting of the members, the air went up from the house into the closets, and out of their chimneys, and continued to do so the whole day, keeping the house very cool." The failure of this plan led to the introduction of the rotatory fan, already noticed (page 182)."*

About the time of the controversy between Dr. Desaguliers and Dr. Hales, respecting the merits of their machines for ventilating ships, as described in the last chapter, a new rival appeared, with a contrivance which far exceeded either of theirs, in point of practical utility, from the circumstance of its being self-acting. Mr. Samuel Sutton, a brewer, being moved with compassion towards the unhappy soldiers who were suffering in the ships at Spithead for want of fresh air, felt himself "obliged to do all that was possible for their relief in these unhappy circumstances," and even submitted to all sorts of slights and humiliations rather than forego his laudable desire to benefit mankind in general, and the navy

* "Sir George Beaumont and some other members observing that the design of cooling the house was frustrated, asked me in 1736," says the Doctor, "if I could not find out some contrivance to draw the hot and foul air out of the house by means of some person that should entirely depend upon me, which I promised to do, and effected; calling the wheel a *centrifugal* or *blowing wheel*, and the man that turned it a *ventilator*."

in particular, by the introduction of his apparatus. Without at all desiring to call in question the humane motive of Mr. Sutton, it must still be confessed, that in the introduction of his apparatus, he had a keen eye to his own interest. Not that this is objectionable in any inventor, for there can be no doubt that a benefit conferred by a man upon his country, is deserving of reward ; but the mixed motive is objectionable—urging the invention forward on the plea of humanity, and, at the same time, asking for a large pecuniary reward. When Dr. Arnott advocates the general introduction of his inventions, on the ground of humanity, the motive is pure and honourable, for he takes out no patent, and hints at no reward ; he seeks only to be useful to his fellow-creatures.

Mr. Sutton's invention is, however, very meritorious, and in his curious and amusing narrative,* we read a minute account of its origin and progress. It originated in the following circumstance. In a room which had three fire-places, the windows and doors were made to fit as tightly as possible, so as to exclude the external air. Having made a large fire in two of the fire-places, it was found that the wind came down the chimney of the third fire-place with such force, as to blow out a candle. This suggested the idea of ventilating the different parts of a ship ; for as a fire is always kept burning on board, it was supposed that a pipe or cavity opening from any part of the ship to the fire, would draw the air along it to feed the fire, thus occasioning a fresh supply to the part of the ship whence the air was subtracted. This idea being once conceived, Sutton sought every opportunity of consulting naval men on the subject of the ventilation of a ship. On

* *An Historical Account of a New Method for extracting the Foul Air out of Ships, &c.* By Samuel Sutton. London, 1745. A second edition was published in 1749, containing two favourable accounts of the invention, read before the Royal Society by Dr. Mead and Mr. Watson, and a Discourse on the Scurvy, by Dr. Mead who thought that that fatal disease would be greatly mitigated by the introduction of Sutton's apparatus on board ships.

one occasion, he says, "being at a coffee-house near the Admiralty, I placed myself nigh some gentlemen of the navy, and inquired of them, as I had before of others, as to the usefulness of the forementioned change of air, who all, to a man, acknowledged that it would be of the utmost service, and upon their unanimous approbation of it, I told them that I could procure such a change of air: upon which one of the company went to another table, and the rest followed him; and I heard him tell the others, that he heartily pitied me as being really mad, and out of my senses." Sutton had solicited an interview with the Lords of the Admiralty, which was granted, and he received a letter of introduction to Sir Jacob Ackworth. On presenting it, a meeting was appointed five days afterwards at seven in the morning. The brewer was punctual, but the knight kept him waiting the whole day, and it was not till the evening that he condescended to exchange a few words with him:—"Sir, I suppose you intend to throw air into the wells of ships?" "No; I propose to draw it out by means of fire." "Do you know how far you are to draw it out?" "Not six inches; for if I can extract it never so small a distance, the incumbent air will press forward, of course, and cause a constant change." Sutton then expressed a hope that a time might be appointed for a trial of his scheme, but the knight replied that no experiment should be made, if he could hinder it. This unmannerly treatment did not daunt the brewer. He petitioned the Lords of the Admiralty, and obtained an order to make an experiment in a ship of war at Woolwich. Whereupon he proceeded to erect his apparatus, and had completed it, except the soldering of two pipes, when a messenger from the builder of His Majesty's yard appeared, and ordered the workmen ashore. In spite of all remonstrances, the work was suspended, and next day the apparatus was taken down, and the holes were plugged up. Under these discouraging circumstances, Sutton introduced himself to Dr. Mead, the king's physician, who at once encouraged the scheme, and succeeded in getting Martin Folkes, the President of the Royal Society,

to favour it. Under this powerful patronage, the Admiralty were induced to order a trial to be made of the apparatus on board any of His Majesty's ships in the river. Accordingly, Sutton fixed upon the hulk at Deptford, but he had great difficulty in getting his orders executed; the workmen of the King's Yard "were busily employed in trying the usefulness of another machine, industriously set on foot to supplant mine;" "the excessive shyness and caution of the gentlemen of the yard led me to conclude that my scheme at last would be set aside, in spite of all the steps I could take to prevent it; and I was confirmed in this opinion when I found the pipes were made of wood between five and six inches wide, in such an unworkmanlike manner, that to render them tight, I was forced to get size and paper from Deptford to put over the joints; and that, moreover, many hands were employed in erecting wind-sails, in order to shew that they could thereby procure as much air as my scheme would afford." But, at length, in September, 1741, the trial was made before some of the Lords of the Admiralty, the Commissioners of the Navy, Dr. Mead, Martin Folkes, Esq., and several other members of the Royal Society. Sir Jacob Ackworth welcomed this distinguished company, by remarking, "I am sorry that you are come to see the trial of such a foolish experiment, that I tried myself yesterday, and it would not shake a candle." Sutton ventured to reply that the apparatus would be in good humour that day, and that the end of every one of the pipes would blow out a candle. The experiment was accordingly made, and although Sutton complains that the tarpaulins which he had placed over the hatches had been removed, the success was complete, and his friends were satisfied.* The

* Mr. Watson reported to the Royal Society, that Sutton's machine brought up air "from the bread-room, orlop and well of the ship at the same time, in such quantity, that large lighted candles being put to the end of the tubes, the flame was immediately sucked out as fast as applied, though the end of one of the tubes was above 20 yards distant from the fire."

result of this trial was, that, in November following, Sutton was sent by the Lords of the Admiralty to Portsmouth to fit up his apparatus in the *Norwich* man of war. Sir Charles Wager gave him a letter to the Commissioner at Portsmouth, in which he sensibly remarks, "this contrivance is approved by much wiser men than I am in such things, and, therefore, I desire you would let Mr. Sutton have all the encouragement and assistance you can give him." He also requests that Sutton may "meet with no obstruction or discouragement from any body that may think themselves wiser." After this, as may be supposed, Sutton had nothing to complain of in the Portsmouth dockyard.

Sutton now thought it high time to ask for a "suitable reward for his useful invention, and reasonable satisfaction for his trouble, loss of time to the neglect of his other affairs, and expenses in the execution of the same." He plied the Admiralty with petitions, but received no answer until the 11th June, 1743, when he was furnished with an extract from a letter from the Captain of the *Norwich*, containing his report as to the working of the apparatus, on a voyage to the Coast of Guinea, the West Indies, and back. The Captain's report is as follows :—"As to the air-pipes which were put on board of me, I was obliged to stop up two of them, by reason the fire came down between decks—the other, to the well, was kept open; but the ship making water enough to keep her sweet, I was not able to judge of their use, having been so healthy as to bury only two men all the time I was on the coast." The healthy state of the crew, during such a voyage, was, at the period to which we now refer, something so extraordinary, that the Captain's report, which was intended to condemn the scheme, is really a high eulogium on it, seeing that one of the pipes was allowed to remain open during the whole voyage.

At length the Admiralty made their report, in which they stated that the apparatus "does not, in all respects, come up to the expectation, and that the use thereof is dangerous and

liable to accidents by fire, yet as the said Mr. Sutton has employed a great deal of pains and time about the said invention for the benefit of the navy, and had encouragement from their Lordships to do so, and their Lordships, being desirous to give encouragement to persons who shall turn their thoughts to any inventions that may tend to the advantage of the navy," directed him to be rewarded with the sum of *one hundred* pounds! Of course Mr. Sutton was very much disappointed, and very angry. He attributes his failure to the undue preference given to Dr. Hales' ventilators.

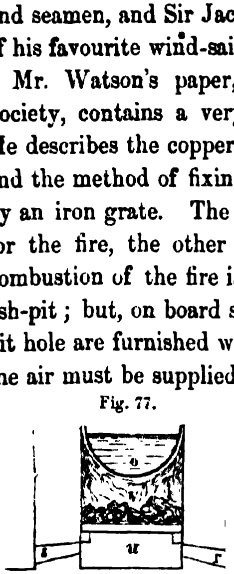
Mr. Sutton received the hundred pounds "on account," and did not cease to urge the merits of his invention upon the Admiralty, until he got an order to have his apparatus fitted to several ships. He then looked out eagerly for the reports of their respective commanders, and was fortunate in getting a favourable return from Admiral Boscawen, dated Table Bay, 9th April, 1748, in which he says, "I cannot help thinking the air-pipes fixed in the men of war have been of great service, by purifying the air between decks, and thereby preventing the scurvy." After this, the career of Sutton was crowned with success, which he modestly attributes to "the wisdom and zeal of the present Right Honourable the Lords of the Admiralty, and the Right Honourable and Honourable the principal officers and Commissioners of His Majesty's Navy, who having taken the whole affair into their serious consideration, were so thoroughly satisfied of the great advantage that must accrue to the nation from the faithful execution of my scheme, that they have contracted with me for fixing my engine on board His Majesty's ships, whether laid up or in commission." As Sutton makes no further complaint we must suppose he was satisfied with the pecuniary part of the arrangement: as to his zeal for the good of his country, which he talks so much about, he took care that no one but himself should derive pecuniary benefit from the plan, by securing his invention by a patent.* This, however, at length, proved

* The application of the machine, as stated in the patent, is for re-

more fatal to the scheme than the powerful opposition of Sir Jacob Ackworth, and the cool indifference of the Lords of the Admiralty. Sutton charged £30 for each ship of the Royal Navy, or of the East India Company, into which the apparatus was proposed to be introduced; and as this was thought too much for a benefit which many persons in authority were disposed to question, the scheme was abandoned in a year or two, and, after the death of Sutton, all trace of its existence seems to have been eradicated from the minds of ship-builders and seamen, and Sir Jacob was left in undisturbed possession of his favourite wind-sails.

Mr. Watson's paper, which was read before the Royal Society, contains a very good account of Sutton's invention. He describes the copper used for boiling the ship's provisions, and the method of fixing it, with two openings below, divided by an iron grate. The first opening, having an iron door, is for the fire, the other for the ashes. In ordinary cases, the combustion of the fire is supported by air drawn through the ash-pit; but, on board ship, as both the fire hole and the ash-pit hole are furnished with doors to prevent the escape of fire, the air must be supplied by some other means. Accordingly,

Fig. 77.



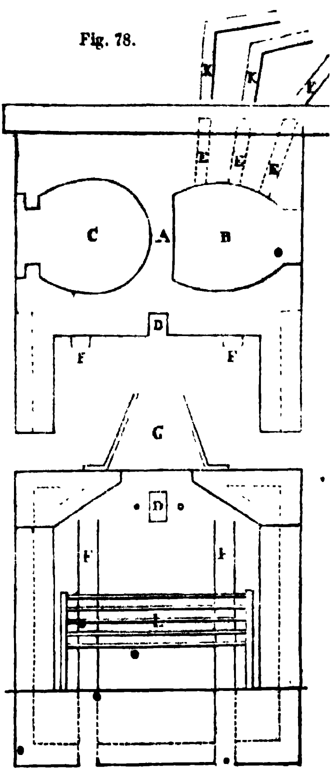
one or more holes, *r s*, Fig. 77,* are made through the brick-work in the side of the ash-pit, *u*, and tubes of lead or copper are fitted closely therein, and conducted from thence into the well, and other parts of the ship; thus drawing off therefrom the foul air, and sending it through the fire, v, it escapes up the chim-

moving noxious air from "mines and caverns in the earth, dungeons, prisons, and all infected places." It may also be used in "hot-houses and walls, which will greatly warm the earth for the speedy production of its fruits, and also in granaries, for the preservation of corn and grain."

* In the plan, Fig. 78, B is the ash-pit, E E the copper pipes opening into it, C the oven, D a vent-hole, and K K the pipes, continued to any part of the ship.

ney. At the same time, a supply of fresh air rushes in at openings about the ship, to occupy the place of the bad air. This circulation of air not only goes on while the fire is burning, but so long as the fire-place, copper, or brick-work remain warm, as was observed on board the hulk at Deptford, when the draught of air through the tube lasted above twelve hours after the fire was taken away. "This being considered, as the dressing the provisions for a number of people will take up some hours every day, the warmth of the brick-work and flues will continue a draught of air from one day to the next, Mr. Sutton proposes thus to circulate the air by the same and no greater expense of fire, than is customarily used for the necessities of the ship." The larger the ship, the greater the number of men on board, and the larger the quantity of provisions, so that more time and fuel will be required in preparing them, and the more perfect will be the ventilation. The size and number of the tubes is of little consequence, for the larger the tubes, and the greater their number, the less the velocity of the air, and *vice versâ*. Mr. Watson notices, as an essential condition of the perfect action of the tubes, that both the fire door and the ash-pit door be kept closed. In large ships there is not only a copper, but also a fire-grate, L, (Fig. 78) like that used in kitchens. Behind this grate, copper tubes, F F, were also

Fig. 78.



fixed and carried through the brick-work, so that one extremity thereof projected about a foot into the chimney, G, and the other end opened into the hold, or any other part of the ship; so that the air rushed along this tube into the draught of hot air in the chimney. To obviate the objection to the space occupied by these tubes on board ship, it is advised that only one tube, of a convenient size, be attached to the side of the ash-pit, and, as soon as it passes through the main-deck, to give it the form which occupies least room; and from this main tube, branches might ramify to different parts of the ship, these branches being carried between the beams which support the deck, till they meet the sides of the ship, where they could be conducted also between the beams into the places intended.

How admirably adapted is this plan to the ventilation of steamers. A large central trunk might be made to feed the furnace, and into this trunk smaller branches from every cabin and sleeping birth might discharge their foul air, and thus maintain every part of the vessel in a state of perfect salubrity. That Sutton's plan has not been entirely forgotten, is evident, from its having been applied in order to get rid of the offensive effluvia arising from the coppers of soap-boilers, tallow-melters, and similar occupations, which often become a nuisance to a whole neighbourhood. The copper is set in the usual manner, and the furnace and ash-pit, furnished with doors, so as to admit of being perfectly closed; the lid of the boiler is made to fit very tight, and a pipe rising from it is carried into a channel which opens into the ash-pit; the fœtid matters rising from the boiler, are in this way made to pass through the fire into the smoke-flue. This plan is said to have answered perfectly, so that a factory which was formerly most offensive, became entirely free from offensive odours.

In the two schemes thus detailed, that of Dr. Desaguliers, for ventilating the House of Commons, and that of Mr. Sutton, for ventilating ships, &c., we have the principle of ventilating

by artificial heat carried out with perfect success. A large number of plans have been subsequently contrived on the same principle, many of them made subjects of patents; and, although it is more than probable, that the respective inventors not only did not copy them from, but had never heard of either of the plans above described; yet, as they are identical in principle, and very similar in detail, it is not necessary to particularize them. A few examples, however, may be noticed of the ventilating of public buildings, and as the House of Commons has often been made the subject of experiment in this way, as already noticed, it may be interesting to state a few particulars respecting the warming and ventilation of the House of Lords.

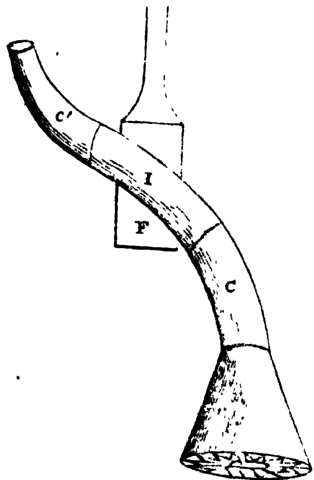
Sir Humphry Davy having been requested to devise some scheme for the purpose, submitted to the Lords Commissioners, in February, 1810, his proposals; and in September, 1811, in a letter to the Earl of Liverpool, he thus briefly recapitulates the heads of his plan:—"To convey fresh air into the House, I propose flues of single brick connected with the flues for sending hot air through the vaults under the floor, and I propose that this fresh air should be admitted by numerous apertures in the floor of the House, and supplied to the flues by pipes of copper or plate iron from the free atmosphere. The air in this case will be always fresh, and, by regulating the fire, may be more or less heated, according as the temperature of the room is low or high.

"To carry off the foul air, I propose two chimneys, or tubes made of copper, placed above the ventilators, and connected with wrought iron tubes, which can be heated by a small fire, if a great draught is necessary, as in cases when the House is full.

"Should this plan be adopted, there would be no necessity for opening windows; the foul air would be carried off from above; warm air or cold air, whichever is necessary, may be supplied from below, and there would not be, as now, any stagnation of air."

The plan accompanying this letter, of which the above is an extract, is shewn in Fig. 79.

Fig. 79.



v is one of the ventilating apertures in the ceiling of the House, covered with a chimney of copper, c; this is continued by an iron tube, I. which passes through a small furnace, F. c is another copper tube connected with the iron one. The upper end of this tube, was only one foot in diameter; it opened into a cowl on the roof. The furnace, F, was contained in a fire-proof house erected for the purpose on the roof.

This plan does not seem to have been very successful; for Mr. Adam Lee, in his Report to the Lords' Committee, in June, 1813, states, that on very crowded nights, it was impossible, by means of the present ventilators, to draw off the heated air; the temperature in the House frequently rose to 80°, and would have been higher if the windows had not been open. Instead of the ventilation pipe, one foot in diameter, it was proposed to erect enlarged pipes of three feet diameter, furnished with registers to close them, to prevent cold air from blowing into the House when the ventilation was not wanted. These pipes were to be conveyed in an oblique direction to the fire-proof house, and to be capped at the top with a cowl-head. The fire to the ventilator was considered unnecessary, and even objectionable, on account of smoke getting into the House down the ventilator. "I have, at various times, taken an opportunity," says Mr. Lee, "of going on the top of the House, and have put my head over the ventilation pipe when the fire was at full heat, and have not perceived the hot air coming from the House. I have likewise tried, at other times,

without fire, and have found a very strong current of hot air from the body of the House.*

Mr. Lee's plan for ventilation was tried and failed. There is no doubt, that after abolishing the furnace, and introducing wide tubes, a down current was as likely to be admitted into the house as an ascending current out of it; and the contriver himself, who thought himself a wiser man than Sir Humphry Davy, has afforded a sufficient satire on his own improvements, by proposing to place rotatory wheels in his wide tubes, in order to make them discharge the air the right way. It is satisfactory to learn, that their Lordships did not accede to this proposal. They consulted Mr. James Wyatt, the architect, who made some changes in the House, and erected some apparatus. This perished in the fire in 1834, which led to the destruction of both Houses.

In the following year, a Select Committee of the Commons examined a number of witnesses, consisting chiefly of scientific and practical men, with a view to discover the best, or, at least, a good method of warming and ventilating the New Houses of Parliament about to be erected. In their Report, the Committee advised that some plan should be systematically adopted before the commencement of the new buildings, from a conviction, that whatever plan should afterwards be selected, "provision should be made for its adoption, in the first instance, by the architect, so as not only to insure its success, but to prevent needless expense and inconvenience;" and that, for this purpose, "the whole space immediately below the two Houses, as well as that between the ceiling and the roof, be prepared and altogether reserved for such arrangements as may be necessary for the object in view." The plans proposed by Dr. Reid, were favourably noticed, and it

* In this Report, it was also stated, that the flues were arranged horizontally round the chamber of the House, 100 feet in length and upwards, and that the smoke remained in them for a considerable time, sometimes producing a strong smell of sulphur in the House itself.

was recommended that some, if not all, of his alterations should be submitted to the test of actual experiment, "as the only means of ascertaining with accuracy the soundness of the principles laid down in the evidence, and their useful application to the future Houses of Parliament."

The temporary building for the House of Commons having been found very defective, in respect both of warmth and ventilation, this building was placed at the disposal of Dr. Reid. It had been warmed by the ordinary warm water system: the large flat tablets through which the water circulated were placed in a room under the House, and occupied a surface of about nine feet square; they were four feet high.

Dr. Reid's arrangements were as follows:—Two or three feet beneath the floor of the House, a second floor was formed, containing about twenty apertures each about eighteen inches square. Beneath the second or lower floor, is a long passage, A; opening into this, are two others of an equal width, B and C; in the passage, B, is placed the warm water pedestal. Large folding doors are placed before the entrances, and within these passages; the temperature of the house above depends on the relative adjustment with each other of these folding-doors. Fresh air, either warm or cold, according to the season, can be produced; and it can be changed from warm to cold, or the contrary, as the variable external temperature of the day or hour requires. This will be understood by referring to the section (Fig. 80), and the plan (Fig. 81). The fresh air enters from Old Palace-yard, through the perforated wall, D. If the folding-doors 1 and 2 are opened, and all the rest closed, the air will enter the passage, A, passing through the pedestals placed in B, and warm air only will be supplied to the house above. If air moderately warmed be required, the doors 3 and 4 are opened in addition to 1 and 2, and two currents, one cold and the other warm, are then produced, which meet and blend together in the passage, A, and then ascend. If air of the external temperature only be required, the doors 3 and 4 are alone opened. If required to be only moderately warmed,

3 and 4 are opened, 1 half opened, 2 closed; the small folding-doors, 5 and 6, are then opened, and a slight current of warm air passes through the small passage E, and mixes with the cold current entering at C. The folding-doors in this passage can likewise be opened when 3 and 4 are closed, and a current of warm air will then be conveyed to one end of the passage A.

The air, whether warm or cool, rises through the apertures *a a a*, into the space beneath the real floor of the house. Immediately over these openings are large platforms, supported by short feet, the effect of which is to disperse the great body of air admitted. The air then enters through openings made in the actual floor of the house, these openings being exceedingly small, very close together, and about 300,000 in number. They are about one-sixth of an inch in diameter on the surface of the floor, but expand downwards, to prevent their being stopped with dirt or dust. The sides of the House under the galleries are battened or brought forward five or six inches, and in the space thus formed between the framing and the wall, the air ascends and passes out through the floors of the members' galleries, perforated for the purpose in the same manner. The floor of the House and galleries is covered with a thick horse-hair matting with large meshes, to allow the air to ascend through them.

The force which sets this great body of air in motion, is the ventilating shaft, G, in which a powerful upward current is generated by means of a large fire, as will presently be explained.

In summer, when the air transmitted into the House is required to be cool, various contrivances can be resorted to in the chamber immediately behind the perforated wall, D. The air might be made to pass into the chamber A, over wet surfaces, and be cooled by evaporation, or ice may be suspended in netting between the piers in the chamber.

A new ceiling was also constructed a few feet below the

Fig. 80.

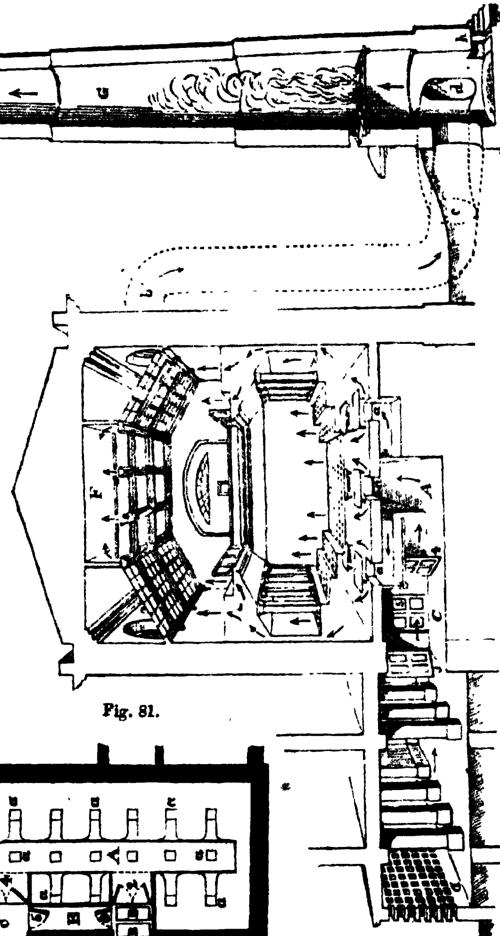
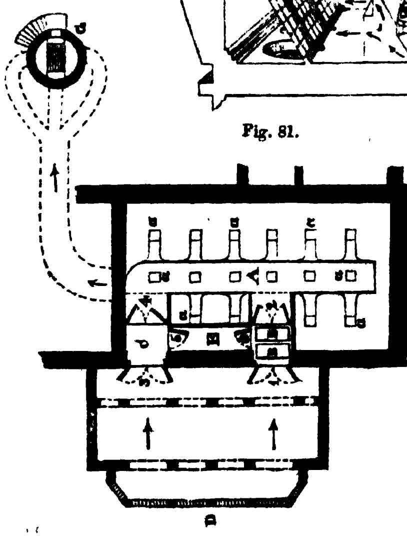


Fig. 81.



former one, for the purpose of favouring the transmission of sound. This ceiling is divided into three portions, the central portion being horizontal from one end to the other; the other two compartments inclined so as to make an angle of 30° with the floor of the house. These two inclined portions are glazed, but the centre is panelled, so as to assist in the ventilation of the House. An inclination has also been given to the ceiling beneath the members' galleries, corresponding exactly with the inclination of the lateral compartments in the newly constructed ceiling above.

The ventilation of the House is accomplished in the following manner:—Each panel of the centre compartment of the ceiling is raised by blocks several inches above their styles, thus admitting the air of the House into the space, F, between the two ceilings. The rapid removal of this vitiated air, and the consequent rushing in of fresh air from below, is effected by the large shaft, G, erected in Cotton Garden, at a distance of about 20 feet from the eastern wall of the building. About ten feet from the surface of the ground is a very large coke or coal fire, which produces a powerful current up the shaft. Now the space, F, between the two ceilings of the House, opens at the north end into a large square shaft, which is continued downwards, and opens underground into the circular shaft, G. The consequence of this arrangement is, that when the current of hot ascending air is produced in the circular shaft, there is a downward draught through the square shaft, thereby rapidly withdrawing the air from within the House, and causing the fresh air to rush into it from openings in Old Palace-yard. A damper at *b*, in the square shaft, regulates the draught in the shaft, G, and consequently, as it is more or less opened, the supply of air to the house can be regulated according to the number of members present.

The height of the ventilating turret above the ground is 110 feet: it is 12 feet in diameter at the base, and about eight feet at the summit.

The system thus described, has been in operation for some

years, and may, we think, be pronounced as one of the most extensive, and, upon the whole, one of the most successful experiments in the warming and ventilation of a building that has been made in this country. The arrangements are made with considerable skill, and display a good knowledge of the subject. That they have not been completely successful need not excite surprise, when it is considered that the plans of some of the most eminent scientific men have been partial failures. That Dr. Reid should have failed in doing what he proposed to do in the case of every building which he took in hand is no wonder, when it is considered that each building presents its own peculiar set of difficulties, and that the facilities are either very few or absent altogether; for, as Dr. Birkbeck remarked, in his evidence before the Committee, "Heating and ventilation, especially the latter, seldom enter into the mind of the builder when he projects his building; he begins as if he did not know that ventilation could be necessary; he trusts to the doors and to the windows, to neither of which belongs the business of ventilation. The doors admit the occupants to the chambers; the windows the light; and apertures ought to be introduced to admit air for ventilation as regularly as the other openings." Or, as Dr. Faraday remarked in another place, "The builder makes the doors and the windows to fit as tightly as possible, and then the poor chemist is called in to provide fresh air." Under such circumstances, the poor chemist can only do his best. The laws of nature will not accommodate themselves to him; he can only apply them as far as they admit of application in a building, where every thing seems to have been arranged for the express purpose of defeating their operation. And even when the best arrangements are made which the circumstances will admit of, their efficient working requires the constant superintendence of a man of intelligence, instead of an ordinary stoker or porter. For if the room, or court, or hall, or church, or whatever it may be, be very crowded, the ventilation must be promoted as much as possible, and the warming restrained. If, on the

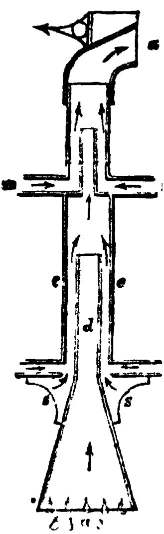
contrary, the building contain only a few persons, and the external temperature be low, the warming must be increased, and the ventilation diminished. To meet all the circumstances of the case, for summer and for winter, for night and for day, without any assistance from the architect who designed the building, and your arrangements constantly exposed to defeat, by careless attendants leaving doors open, or by people constantly coming in or going out—to do all this to the satisfaction of every one, is a task which few scientific men would undertake. It is now the fashion to cry down Dr. Reid, and to call him by all sorts of ugly names: this is very easy, as is every kind of criticism which consists in mere abuse and fault finding; but, although we are no partisans of Dr. Reid, we venture to state our opinion, that in the case of the temporary House of Commons, where all the arrangements were left in his own hands, he has succeeded in the proposed object of removing the vitiated air, and keeping up a constant supply of warm or cool air to fill its place. The following extract from a Parliamentary document contains, in few words, both the praise and the censure of this system, and with this we take leave of the subject.

"A strong current of prepared air is now admitted, immediately under the entire surface of the floor, which is pierced with many thousand holes: after passing through these apertures, the air is again distributed into many millions of other holes, by means of a hair-cloth carpet, through which it is drawn up towards the ceiling, where admirable arrangements have been made by Dr. Reid, for discharging it through apertures in the edges of the panels; and thus the foul air is carried rapidly along a tunnel to feed the great furnace which creates this current of ventilation. It is obvious, that the air so drawn up through the hair-cloth carpet must be charged with particles of ground dust or mud from the members' feet; and that (so impregnated), it must be inhaled by those within its reach. I heard many members complain that it rests upon their faces, and enters their eyes, and nostrils, and mouths;

and from woful experience, some members know that it can find its way to their lungs."*

In theatres and similar places, where a large central chandelier is used for the purposes of illumination, advantage may be taken thereof as a powerful ventilating agent. This was done many years ago by the Marquis of Chabannes, who was engaged to warm and ventilate Covent Garden Theatre, and his arrangements will be understood by referring to Fig. 82, in which *a* is the chandelier; *d*, a pipe of wrought iron for the purpose of carrying off the heat and the products of combustion; *e*, a wooden case, into which air flows at *o* and *s* from the ceiling; *m m*, pipes which conduct the vitiated air from other parts of the house. In one of the galleries was placed a furnace, the combustion of which was supported by the vitiated air from several tiers of boxes. A similar furnace was placed over the stage, and the gas chandelier ventilated the centre. The vitiated air from all parts of the house was discharged above the roof, through three trunks, each terminating in a cowl, *u*. The air admitted into the theatre, to replace that which was carried off by this powerful ventilating apparatus, was warmed by means of a furnace, called a calorifère, placed at every entrance and staircase which communicated with the external air. The stage, and the parts behind the curtain, were warmed by steam cylinders placed below the stage. Calorifers were also placed at every other point, whence a draught of cold air was likely to issue. The effect of all these arrangements was, upon the whole, satisfactory, and it is certain that this theatre was

Fig. 82.



* Sir F. Trench to Viscount Duncannon. *Par. Pap. No.* 204, *Sess.* 1838.

better warmed and ventilated than any other in London. Complaints, of course, were made. The atmosphere of the house was said to have a dry and stifling effect; and, no doubt, in cold weather the air must have been dry, for if admitted at and below the freezing temperature, and then warmed to 65° before it was inhaled, it would feel dry. But those who complained most loudly, probably, never inquired whether pure dry air at 65° is not far better fitted for the purposes of respiration, than the vitiated air of crowded assemblies, the moisture of which is of the most offensive character.

The preceding details will sufficiently illustrate the principle upon which ventilation is conducted when fire or flame is used as the force to give motion to the ventilating current. The use of hot water, steam, &c., as ventilating agents, will be noticed in the next chapter. There are one or two special applications of ventilation, in which flame and fire are concerned, which belong to this chapter; these are the ventilation of lighthouses and of mines.

Until within the last seven or eight years, no provision was made for the ventilation of lighthouses, a neglect or oversight the more extraordinary, when it is considered that the efficiency of a lighthouse depends on the brilliancy of the light exhibited, and this, in its turn, depends on the perfection of the combustion. If no means be taken to carry off the products of combustion, they must accumulate within the lantern, and greatly interfere with the usefulness of the light, as well as injure the health of the attendants.

Let us consider for a moment what a lighthouse is, and what are the nature and amount of the products of combustion generated within it. A lighthouse may be defined as a small room raised to the top of a tower sufficiently strong to resist the action of the waves and wind, as in the Eddystone, and the wind in all cases; to bear all the beating and pelting of the storm, and yet to be only walled with glass. Within this transparent room or lantern, a brilliant light or many

brilliant lights must be kept constantly burning during sixteen hours on a winter's night, and during eight hours in summer. According to one arrangement, a large and very powerful lamp is fixed in the centre of the lantern, and this burns or consumes from 12 to 14 pints of oil in one hour. According to another arrangement, 20 or 30 small Argand lamps, each with a polished reflector behind it, are mounted on a revolving frame, and these consume from 15 to 20 pints of oil in one hour.

Now as oil in every 100 parts contains 78 parts of carbon, 11.5 parts of hydrogen, and 10.5 of oxygen, it will be seen that the products of combustion must chiefly consist of water and carbonic acid. Now there is enough hydrogen in 1lb. of oil to produce rather more than 1lb. of water; because, 1 part of hydrogen combines with 8 parts of the oxygen of the air to produce 9 parts of water.

The 78 parts of carbon in 1lb. of oil will, in like manner produce $2\frac{86}{100}$lbs. of carbonic acid; that is, the carbon will deprive the air of nearly 3lbs. weight of its oxygen, thus spoiling $13\frac{1}{4}$lbs. or $172\frac{1}{2}$ cubic feet of air, by depriving it of its oxygen.

Such being the products of combustion of 1lb. of oil, it is easy to ascertain the products of the combustion of $19\frac{6}{10}$ pints of oil, the quantity consumed per hour in the Tynemouth lighthouse. The most obvious inconvenience arises from the water, of which not less than 20 fluid pints are produced per hour; for that is the given quantity, if the vapour, as it is given off, were condensed. Now the lantern itself, in cold weather, affords a powerful means of condensation, especially when a cold frosty wind is blowing upon it. In such case, the vapour is not only condensed into water, but the water is frozen, and the plate glass of the lantern is often covered with a crust of ice, varying from a quarter to half an inch in thickness. If this ice were perfectly pure and transparent, it would dim and distort the light; but the vapour of water from the oil carries with it minute particles of carbon or soot, which

condense with the water, and become entangled with the ice, thereby producing a further opacity. The carbonic acid is chiefly injurious to the attendants. The men at the Eddystone lighthouse told the writer, some years ago, that during the long nights of winter, they had great difficulty of breathing in the lantern, and that the "foul air" descended into the sleeping apartment below, and produced great inconvenience. They also complained of the enormous amount of labour which they had every morning in cleaning the glass panes of the lantern, and the difficulty of getting rid of the ice. It was sometimes even dangerous to scrape it off, from the risk of fracturing the glass.

The attention of the Trinity Board had long been directed to the removal of these evils, and about the year 1842, they requested Dr. Faraday to turn his attention to the subject. He did so, and after visiting various lighthouses, and making himself master of all the facts of the case, he devised a remedy as simple and complete as could be desired. The results of his investigation were given by him to the members of the Royal Institution, in a lecture, on Friday evening, the 7th of April, 1843, which the writer had the privilege of attending.

In those lighthouses containing a single lamp in the centre of the lantern, the remedy consisted in lengthening the chimney of the lamp, or rather in placing over the glass chimney a tube of sheet iron, and carrying it through the roof of the lantern into the open air, the upper extremity of this tube being defended from the weather by a cover of some kind. In the other arrangement, a central chimney was also constructed, and over the glass chimney of each lamp was placed one extremity of a small tube, and this tube was curved in such a way, that the other extremity opened into the central chimney. These tubes, one for each of the 20 or 30 lamps, were supported by the frame which carried the lamps and their reflectors, and as the frame revolved, the ends of the tubes described each a small circle within the central chimney

without touching it. In this way the small tubes carried off all the products of combustion, without interfering with the reflectors. The result in both cases was perfect, the central chimney over the large lamp carried off all the products of combustion; and the short tubes over the lamps in the revolving lights also discharged the products of combustion into the central chimney, and this conveyed them to the outer air. The consequence was, that the interior of the lantern was always dry and healthy, and the windows remained perfectly bright. This system, as Dr. Faraday well remarked, may be called an adaptation of *sewerage* to the atmosphere; aërial sewers are employed to carry off the refuse of the spoiled air, instead of allowing it to accumulate in the house or apartment.

The success which attended this simple and beautiful application of ventilating chimneys, suggested to Dr. Faraday its introduction into dwelling-houses, for the purpose of completely and effectually discharging into the external air the products of the combustion of gas lamps. He was, moreover, incited to this, in consequence of an application from the Managing Board of the Athenæum Club, who found that in the library of that institution, the bindings of many of the books, especially of those on the upper shelves, were very much corroded, an effect which was attributed to the products of combustion arising from the gas lamps with which the library was lighted. Now 1lb. of ordinary London gas produces, during combustion, as much as $2\frac{3}{4}$lbs. of water, rather more than $2\frac{1}{2}$lbs. of carbonic acid, and takes from the atmosphere $2\frac{1}{4}$lbs. of oxygen; thus spoiling $19\frac{1}{3}$lbs. of air, or 251 cubic feet. But in addition to these products, sulphurous acid is also sometimes produced, owing to the presence of certain sulphurous compounds, which are not wholly removed in the process of purification. This sulphurous acid, in contact with the air, becomes converted into sulphuric acid, which attacks walls, furniture, books, &c. Dr. Faraday collected some of the watery products of combustion from the gas-burners at the Athenæum, and found it to contain sulphuric acid; the ventilating tubes

placed over the flame were corroded by the acid water in the places where it condensed, and formed a solid sulphate within the tube, of iron or of copper, according to the metal used. But Dr. Faraday did not attribute the corrosion of the books entirely to this source, but partly also to the heat, and partly to certain substances used by the leather dresser.

It is common to see in shop windows large glass bells suspended over the glass chimneys of gas-burners. These are, of course, of no use in carrying off the products of combustion, but merely serve to prevent the flame from blackening the ceiling. But if a pipe from the top of each lamp be led out into the open air, or into the chimney of the room, not only are the products of combustion carried away, but the gas-burners themselves often become powerful and efficient ventilators to the whole apartment, instead of being, as before, a powerful source of vitiation. The inconvenience to be guarded against is the condensation of water in the pipe, for at a short distance from the gas flame, the watery product of combustion becoming cooled, condenses into water before it reaches the extremity of the ventilating tube; and if the tube ascends all the way from the burner, the water will even flow back and extinguish the flame, or otherwise annoy the persons in the room.

But as the appearance of these ascending ventilating tubes in a room is rather unsightly, Dr. Faraday got rid of them altogether, by making the hot air from each burner descend instead of ascending. This he accomplished by furnishing each burner with two concentric glass chimneys of unequal height, the lower one being the interior. The exterior or higher of the two chimneys is covered with a plate of mica, so as to prevent the draught from ascending higher than the top of this chimney. The descending current is established by applying heat to the bend of a ventilating tube, fixed at the bottom of the two chimneys, and turning upwards among the ornaments of the chandelier. When this current is fully established, the gas is lighted, and the mica plate placed over

the outer chimney. Each Argand burner is supplied with air in the ordinary way, through the centre, and the products of combustion are carried from the top of the inner chimney, down through the space between that and the exterior chimney, then along the descending ventilating tubes up into a central vertical shaft, which serves also to suspend the chandelier and to enclose the gas pipes; the products of combustion are then received into a box above, and from this proceeds a pipe into the open air. A globe of ground glass, open only at the bottom, is placed over each lamp, and has an elegant though unusual appearance. It is said, that the two glass chimneys produce more perfect combustion, and, consequently, a greater amount of light, than with an ordinary Argand burner, with only one chimney. The flame is certainly larger, and of a redder colour than the ordinary gas flame.

The ventilation of a coal mine is regulated on the principle of descending and ascending draughts. The reader is aware that those enormous deposits of coal which form so large and important a portion of the mineral wealth of Great Britain, are called *coal-fields*, in which the coal, situated at various depths from the surface, is separated into a number of distinct layers or strata, of various thicknesses, by means of layers or strata of slaty clay, called *shale*, and coarse hard sandstone, called *grit*, forming altogether what are called *coal-measures*; or, in other words, beds of sandstone, shale, clay, and coal, lie one above another, in repeated alternations, to a great depth. The strata of coal, however, technically called *seams*, are very thin, compared with the other associated beds. Though extending under large tracts of country, they are often only a few inches thick, and never more than six or eight feet, except one seam in Staffordshire, which is thirty feet. But the interposed strata of grit and shale often exceed 700 feet in aggregate thickness. Under this series, is the mountain limestone, forming various calcareous strata of variable thickness, sometimes exceeding 900 feet. This limestone rests on a bed of old red sandstone, varying in thickness from 200 to

2,000 feet. The term, *coal-formation*, sometimes includes these two great series of strata, although, in general, the coal measures lie above them, the lowest coal-seam commonly resting immediately on the mountain limestone.

The various deposits which form the coal-measures, do not occur in regular horizontal unbroken planes. When first deposited, they were doubtless in this condition, but, at various times, this horizontal position has been disturbed by some upheaving force from below, whereby the coal-measures have, in many districts, been made to assume the shape of a huge trough or basin, rising on all sides from a central point, the sides of the basin being composed of sandstone or limestone, and the middle filled up by strata superior to the coal-measures, such as magnesian limestone, and new red sandstone. Now, it must follow from this arrangement, that the edge or boundary line of each stratum must appear at the surface somewhat like the concentric layers of an onion cut in two. This "coming to the day," or appearance of the coal at the surface of the ground, is called the *basset* or *outcrop*, and serves to determine the outer form or side of the basin. But the internal upheaving force (whatever it may have been) which converted the horizontal strata into basin-shaped arrangements, seems, at the same time, to have produced certain fissures or fractures, often nearly vertical, and stretching through the whole mass. These rents are called *dykes*, because they divide the seams or bands of coal into *fields*, and some of them are so considerable, as to find a place in geological maps.

In order to ascertain where the deposit of coal is most advantageous for working, boring is resorted to, and when the spot is determined, a cylindrical or elliptical shaft, from 10 to 15 feet in diameter, is sunk. The depth may vary from 25 fathoms (150 feet) to 300 fathoms (1,800 feet) before the seam intended to be worked is reached. When this is done, the sinking of the shaft is discontinued, and a broad straight passage, called a *bord* or *mother-gate*, is driven from it into the seam of coal in opposite directions. This bord is 12 or 14

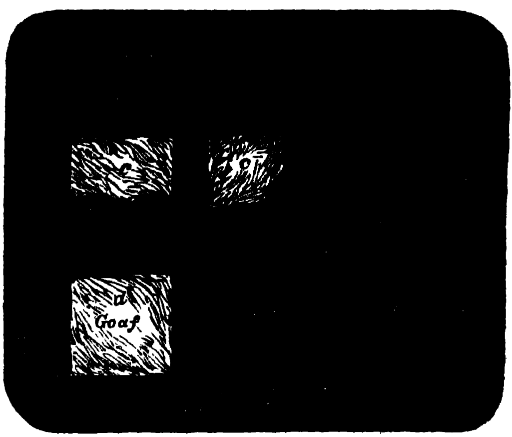
feet broad, and of the whole height of the seam, so as to expose the rock above, which is now called the *roof*, and also the stratum below, which forms the *thill* or floor. It is also necessary to drive a passage, called the *drip-head*, *dip-head*, or *main level* for collecting the water of the mine. From this level gallery, numerous other galleries are driven towards the rise of the strata, till they reach either the outcrop of the seam, or the dip-head gallery of an adjoining colliery. The direction of the bords is arranged so as to follow the natural cleavage of the coal, which forms their sides, and, consequently, is not always at right angles with the dip-head. When a bord has been excavated some distance, narrow passages, called *head ways*, are driven from it, at regular intervals, on both sides, and exactly at right angles, if the natural cleavage of the coal be cubical, as it generally is; and when these have been driven eight or ten yards, they are made to communicate with other bords, which are opened parallel to the first, and on each side of it. In this way, the bed of coal is entirely laid open, and intersected by broad parallel passages, about eight yards apart, communicating with each other by narrower passages or headways, which cross them at right angles, and also traverse the whole extent of the mine, breaking up the seam into immense square or rectangular pillars, which are left standing between the two. In this state, a coal mine has been aptly compared to a regularly built town, the bords being the principal streets, the headways the narrower streets which cross them, while the pillars of coal form the masses or blocks of buildings.

As these pillars of coal form frequently as much as three-fourths, and never less than one-third of the whole seam, many methods have been contrived for removing them without danger. The best method of working, is that called *panel-work*, by which the mine is divided into districts or panels, separated from each other by walls of coal forty or fifty yards thick. The coal is extracted from each in succession, beginning usually with the one most distant from the shaft. Large

pillars of coal are first left between the bords to support the roof; the pillars themselves are then removed, the roof being supported in the mean time by wooden props, and the place where these props replace a pillar is called a *jud*. In time, the jud is removed, and then the unsupported roof of the mine falls in. The heap of ruins thus occasioned by the successive drawing of contiguous juds, is called a *goaf*. Corresponding with this heap of rocky fragments, and produced by it, is a cavity in the mine, like an inverted basin, including a thin belt of air, which surrounds and partly permeates the goaf. This has been the source of dangerous accidents, as will be noticed hereafter.

Fig. 83 is the plan of one story of such a mine, in which

Fig. 83.



the panels, *a a a a*, are not entirely laid open by galleries; *b b* are laid open, but no pillars as yet removed; in *c c*, the pillars are being extracted, and the roof is falling in, its ruins forming a *goaf*; the panel, *d*, is entirely worked out and abandoned.

When the prospects of the mine appear to be favourable, another shaft is, in some cases, sunk at some distance from the first, and when a communication has been established between

them, one is made the *downcast*, and the other *upcast*; that is, the air is conducted from the downcast shaft through all the bords and workings, which it is made to traverse in succession by means of *stoppings* or doors, in various places, to obstruct its passage and give a proper direction to the current in passing to the upcast shaft. The force which sets this ventilating current in motion, is a large fire kept constantly burning in some part of the upcast shaft. The supplies of fresh air, passing into a mine, must, of course, vary considerably. In the Wallsend colliery, they vary from 2,000 to 3,000, and occasionally 3,800 cubic feet per minute. In some of the large workings, the air has to traverse many miles of gallery before it reaches the upcast shaft, and is frequently twelve hours in doing so, moving at the ordinary rate of 2 or 2½ feet per second. Many coal mines are worked without this second shaft, its place being supplied by dividing the single shaft into two distinct portions, by means of an air-tight partition, called a *brattice*, one division being downcast, and the other upcast. The larger shafts (those 15 feet in diameter) are sometimes divided into three parts, one of which is used for raising the coal to the surface, another for working the pumps for the drainage of the mine, and a third for ventilation, for bringing up the air that has passed through the workings.

The necessity for perfect ventilation in a coal mine is more urgent than in other mines, on account of the escape from the coal of large quantities of carburetted hydrogen gas (called *fire-damp* by the miners), which, mingling with the air of the mine in certain proportions, forms a mixture which explodes on contact with flame. This gas is very much lighter than common air, mingles readily with it, and when poured out into the workings, moves along with the ventilating current in the direction of the upcast shaft. The quantity of gas thus poured out is very considerable, but subject to great variation, some seams being more *fiery*, or full of gas, than others; and, in working these fiery seams, it is not uncommon for a jet of inflammable gas to issue from every hole made

for the gunpowder used in blasting. But, in addition to this constant supply, there is danger of sudden discharges from cavities in the coal, laid open by the hewer's pick-axe. The gas issues from these cavities with considerable noise, and forms what is termed a *blower*. These blowers are sometimes so constant in their action, that the gas is collected and conveyed by a tube into the upcast shaft, continuing for months or years to pour out hundreds or thousands of hogsheads of fire-damp per minute. When thus provided for, the blowers are not, necessarily, a source of danger; but when one of the reservoirs containing the pent-up gas of centuries, and consequently under an enormous pressure, is suddenly broken open, the gas is set free in torrents, and, mingling with the air of the mine, forms an explosive mixture which the first spark or naked flame may ignite, and thus cause a fearful destruction both of life and property. Nor is the explosion itself always the thing to be dreaded most; for the ignition of the fire-damp kindles the coal-dust, which always exists in great quantities in the passages, and, in a moment, causes the mine to glow like a furnace. This conflagration is necessarily succeeded by vast volumes of carbonic acid, or *choke-damp*, as it is emphatically called, from its suffocating character, and this destroys those whom the explosion had spared.

It was to guard against accidents of this character, that Sir Humphry Davy invented his safety lamp, a beautiful and simple contrivance, consisting merely of a common oil lamp, the flame of which is completely enclosed within a cylinder of wire gauze, a substance which will not admit of the passage of flame; so that although the lamp be introduced into an explosive mixture, the flame will not pass through the gauze to ignite it. Of course, the efficacy of the lamp depends on the soundness of the wire gauze, for if this be broken and injured, the flame is not protected; or if the lamp be moved swiftly through an explosive atmosphere, the flame may be blown against, and even through, the meshes of the gauze, and, in either case, might lead to an explosion. When the lamp burns

in an atmosphere highly charged with fire-damp, the gas gets within the meshes, and burns with a blue flame, which heats the wire gauze to redness. Even this state of the lamp will not produce an explosion, but of course it was never intended that the workman should go on working with the lamp in this state. The blue flame within the lamp ought always to be a caution to him to retire, until the mine be rendered safe by ventilation. From too great reliance, in all cases, on the Davy lamp, from neglect, and from various other causes, this lamp has disappointed the expectations of those most interested in its use, and experienced men now look for safety rather to improved methods of ventilation than to contrivances for lighting the mines. The general plan of ventilation now in common use will be understood from the following details, in addition to those already given.

When a seam is begun to be worked, there is, of course, only one available shaft for ventilation, and this is divided into two portions, as at *a b* (Fig. 84), for the ascending and descending currents: and as it is not safe for the men to be ever more than a few yards in advance of the course of the current, they begin working the seam with two parallel bords, connected at intervals by cross passages, which are successively stopped by wooden partitions, *c c c*, leaving no communication except through the one last opened, or that which is farthest from the shaft. Temporary partitions are also placed at *e e*, to direct the current to the very spots where the men are at work, as at *w w*. When the workings are more advanced, the direction of the current through every part, by *stoppings* or partitions, becomes a matter of no small complexity, as will be seen by the plan (Fig. 85), where the arrows represent the course of the air from the downcast shaft, *a*, through all the galleries to the upcast shaft, *b*. It will be seen, that in most places the current is divided between the

Fig. 84.

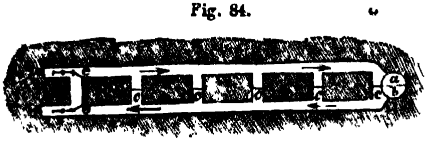
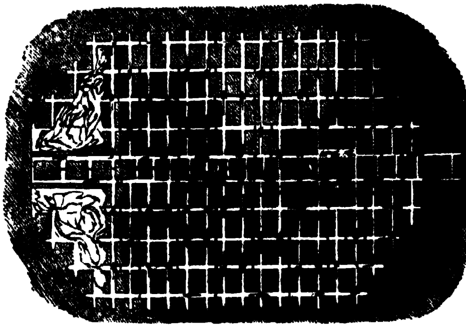


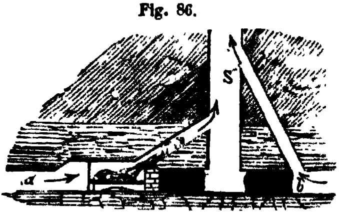
Fig. 85.



parallel bords; this is called *double coursing*, and its advantage is, that if any part of the mine is more fiery or dangerous than the rest, the current can there be confined to one course, and thus have its velocity doubled; while in the parts containing least gas, the same current can be allowed to expand into three passages, which is called *treble coursing.* The double stoppings in Fig. 85, represent those in which doors of communication are required. These are made in pairs, in order that a person may pass through them, as a barge through a canal lock, without allowing the main bodies of air to communicate. To ensure this, they are sometimes made even treble, and a boy is placed in charge of each pair or set of three, whose duty it is to prevent them from being all opened at once.

As it is not safe to allow the foul air from the more fiery parts of the mine to come in contact with the fire at the bottom of the upcast shaft, which sets the whole ventilating current in motion, it is usual to divide the air as it enters the mine by the shaft *a*, into two distinct currents, one of which proceeds through the passages, *e e*, into the safe parts of the mine only, while the other, *c c*, circulates through the fiery parts represented by the lighter shade, including the goafs, or old abandoned workings, which are always the most dangerous receptacles of gas. The purer current alone is allowed to pass through the furnace, *f*, before entering the upcast shaft, *b*. The other current is conducted through *d*, and enters the shaft at a higher level by a tunnel cut obliquely through the roof of the seam, as in Fig. 86, where *s* represents the upcast

Fig. 86.



shaft, B the impure current, and A the purer current, feeding the furnace, which, when thus constructed, is termed a *dumb* furnace.

The goafs, or abandoned workings, are sometimes of vast extent, and are known to occupy from thirteen to ninety-seven acres of ground. They may be compared to enormous inverted bowls or basins, in which the inflammable gas from various parts of the mine accumulates, and from its lightness occupies, at first, the upper part of the goaf: as it increases in quantity, or even as the atmospheric pressure diminishes, it may suddenly fill the goaf and issue from its lowest edge as from the edge of an inverted bowl, and, mingling with the air of the mine, form an explosive mixture, thus giving rise to many sad accidents. Such appears to have been the origin of the explosion in Haswell colliery, Durham, in September, 1844, by which ninety-five persons perished. Dr. Faraday, who, in conjunction with Sir Charles Lyell, visited the mine after the accident, with a view to devise some remedy against the recurrence of similar accidents, recommended that the goaf itself be ventilated. He thought it would not be desirable to attempt this by driving the contents of the goaf through any parts of the mine which are occupied by human beings; but that the goaf cavity might be exhausted of noxious air by means of a pipe, rising as high as possible, from four to eight or ten feet into it, and communicating at its other extremity with the upcast shaft.

Some interesting remarks respecting this explosion, and on the ventilation of coal mines, were made by Dr. Faraday, at the Geological Section of the British Association, in 1845. Dr. Faraday remarked, that the more he pursued the inquiry into the means of preventing such accidents, the more he was disheartened at the apparent hopelessness of finding out any good general remedy. The explosions were not simply the effects

arising from the mixture of gases, but from the combustion of the coal dust and coal gas which the first explosion made. In the fatal case at Haswell, the place where the accident originated had been ascertained, and the progress of the fire could be traced on the scorched beams and props of the galleries, and by the deposits of coke made from the coal dust which the explosion raised. To this circumstance, the great force of the explosion was due, and not to the first escape of gas. A similar explosion had been known to take place in a cotton-wadding manufactory, the whole atmosphere of the place being fired by means of the particles of cotton in it. Of all the workmen killed in the Haswell accident, perhaps not one was really burnt to death, but suffocated by the choke-damp. In one part of the workings, the explosion had produced sharp vibrations, like the firing of gunpowder; and in another, the burning went on slowly, like a common fire. But, although two panels were blown into one, and solid stoppings of brick-work thrown down, there was no indication of accident in the shaft. If the stoppings had not been blown down, and the supply of air had continued, the mine would have taken fire, and the men been burnt instead of choked. Since the late investigation, many hundred plans had been submitted, urging ill-considered and contradictory measures. Every part of the Haswell Colliery had been examined, accompanied by the mine-viewer, and recommendations had been received from the best informed men on the spot; and they were convinced, that the conditions under which such accidents happen were so variable, that no general practical rule could be obtained. Far more information, however, was required. The plan of splitting the air courses was good, as far as the power of the upcast shaft admitted; but if carried too far, it would produce stagnant points, which could not be prevented by any arrangement consistently with the ever-moving condition of the works. The abolition of the use of gunpowder and lighted candles, would, in some cases, double the price of coals. But the great source of danger, was the

mental condition of the miners. With regard to the present race, this was so hopeless, that nothing could be done for them. Although smoking was strictly forbidden, they had been known to contrive to light their pipes in dangerous workings even from the Davy lamp; and Dr. Faraday had himself, on one occasion, sat down with an open candle, to watch the preparations for blasting, and when he inquired for the gunpowder, was told he was sitting on it. Dr. Faraday expressed his opinion of the safety of the Davy lamp when properly used, and of its being a complete and practical contrivance, to which he would willingly trust his own life, as he had already done on many occasions.

CHAPTER III.

ON THE METHODS OF VENTILATING BUILDINGS BY MEANS OF HOT WATER, LOW AND HIGH PRESSURE STEAM, AND BY CONDENSED AIR.

It is proposed, in the present chapter, to give a brief account of the methods which have been contrived for ventilating buildings by means of steam and hot water, at low as well as at high pressures.

The Houses of Parliament have frequently been made the subject of experiments in the art of warming and ventilation. That the experiments have not always succeeded has been already seen, and the reason, probably, has been in their novelty. The members of either House, whose province it has been to order the erection of the various descriptions of apparatus, cannot fairly be charged with the failure, since it is reasonable to suppose, that if a tried and approved method had existed, it would have been ordered; and the reports published on the subject, do not disclose any method which may be pronounced perfect.

The centrifugal wheel of Dr. Desaguliers continued to be used for ventilating the House of Commons, until the year 1820, when the Marquis of Chabannes was allowed to undertake the warming and ventilation of the House. He proposed to erect a small furnace over the ceiling, the combustion of which was to be supported entirely by the vitiated air of the House; but this plan being objected to, he caused a large case or trunk to be constructed over the body of the House, below the roof, into which ventilating tubes were conducted from different parts of the House; four of these tubes opened from under the galleries, to prevent the stagnation of the impure air in those parts, and six openings in the ceiling led into the main trunk, and were each continued in separate trunks to the top, so that the draught from every part was equal. Sixteen steam cylinders were placed within the main trunk, and the heat thereby produced was intended to rarefy the air in the ventilating tubes so powerfully, as to cause its quick ascent and escape through a large cowl of four feet diameter outside the building.

The House was warmed by means of twelve steam cylinders ranged under the seats of the House, and the external air was brought to these cylinders by a large air trunk, from which there was a separate branch to each cylinder.

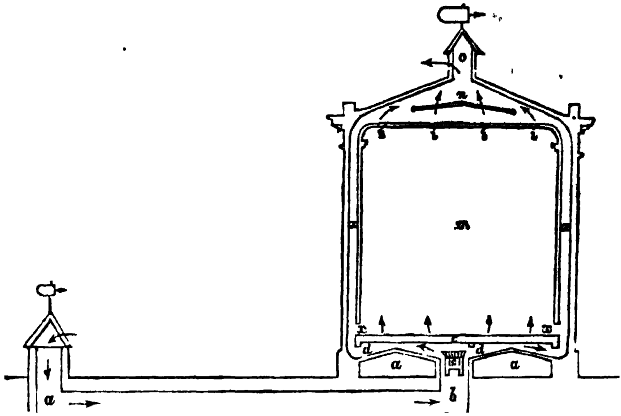
In these arrangements, there was no deficiency either of heating or of ventilating power. On the contrary, the heating surface seems to have been in excess, and was not under perfect command. At any rate, the atmosphere of the House was declared to be uncomfortable, and, after a few years, another system was tried.

The use of hot water, as a means of ventilation, was introduced by Mr. Deacon, in 1813. The air was drawn from an underground tunnel or cellar, by means of a fan, which forced it into the rooms through small iron or earthenware tubes placed in boiling water. The vitiated air was conducted into a tube or channel at the ceiling, and conveyed above the roof, where it was practicable to do so. Iron plates were also

sometimes used instead of pipes. They were placed parallel to each other, with a space of about 1½ inch between them. These plates were surrounded by boiling water, and the air rose in the space between them. When cold air was desirable, the pipes or plates were immersed in cold or artificially cooled water, and the air thus cooled was thrown into the room by the fanner. If the room was of large size, the fan had to be turned by a man; this is, of course, objectionable, because human machines are not always to be depended on. and they are, for such purposes as turning a wheel, expensive. Smaller fans were kept in motion by the elasticity of a spring, or the fall of a weight. Mr. Deacon's apparatus was fixed in some public buildings, but does not seem to have made any permanent impression on the public mind.

Among the plans submitted to the Committee of the House of Commons, in 1835, for warming the Houses of Parliament, that of Mr. Sylvester appears to have great merit. It was not a mere theoretical plan, for it had been tried, although on a smaller scale than that now proposed, in the lunatic asylum for Kent. The general principle of this plan is to introduce the fresh air slowly, and in any required quantity, by means of an underground channel, *a b* (Fig. 87). about 9 feet square, and 100 yards in length, which forms a communication with the atmosphere and the basement floor of the building; the outer extremity of the channel being furnished with a cowl, arranged so as always to have its mouth to the wind. The fresh air flowing along this long tunnel, would receive in winter an accession of about 15° of heat, and in summer it would be cooled to a similar extent. It would then pass into a cockle similar to that of the Belper stove (page 118), where it would be heated to within 5° of the temperature required in the House. From this cockle, it would spread into the space, *d d*, under the floor, and then rise through a large number of small holes drilled in it, into the body of the House. The vitiated air would then be carried off through a number of openings, *i*, in the ceiling, arranged so as to be opened or

Fig. 87.



closed at pleasure, by means of a contrivance communicating through x to the basement. The vitiated air, after passing through these openings, would flow into the cavity, n, below the roof, and thence be discharged into the open air by the turncap, o, formed so as to have its mouth always turned from the wind. To ensure the required velocity and direction of the ventilating current, a series of pipes, n, filled with steam or hot water, were to be placed in the cavity of the roof. When it was required to raise the temperature of the House higher than usual, the amount of ventilation was to be diminished by closing the apertures in the ceiling, and allowing the vitiated air to escape through channels, x x, in the walls. The velocity at which it was proposed to set the air in motion through the channel, for supplying the fresh and discharging the vitiated air, was 4 feet per second; but it was to flow into the House at the rate of only half a foot per second, thereby producing a current which would scarcely move the flame of a candle. The area of the apertures distributed throughout the floor would be about 665 feet; and including the House, the staircases, and corridors, &c., it was calculated that there would be 200,000 cubic feet of air changed six times per hour. When asked whether he proposed to make

any arrangements for securing the purity or cleanliness of the fresh air to be introduced, Mr. Sylvester replied, that it would be extremely desirable to have a communication with some large inclosure for the fresh air, such as a large building like Westminster Hall, between the House of Commons and the outer air, that the air might be admitted into this large inclosure, and allowed to settle and deposit its blacks or smuts, just as water, before being used, is allowed to deposit its mud and sand in a large cistern.

Most of the plans for warming and ventilating buildings, which have been described in these pages, are on a very large and comprehensive scale, adapted to public buildings, and requiring not only a considerable expenditure of money, but also of space for their erection and effective action. By distributing the heated air over the whole of the under surface of a perforated floor, it is thereby distributed throughout the space required to be warmed; and by providing some powerful ventilating force in connection with the top of the building, also perforated, the warm or cool current can be made to pass through the building with any required velocity. But it is obvious, that such extensive arrangements are not adapted to a small building or a private house. In such cases, different arrangements must be made, and these are not always successful. If, for example, the air be heated by stoves, and instead of being sent into the room through a perforated floor, it is admitted in small currents at an elevated temperature, it ascends rapidly to the ceiling, and expends the greater portion of its heat on that surface, while the lower part of the room remains cold, because airs of very different temperatures do not readily mingle together. On this account, Mr. Perkins recommends, that the tubes used in ventilation be placed at or near the floor, by which means the warm air is forced to descend and mingle more intimately with the colder air in the room; and the warm air having thus parted with its heat, is itself drawn off. When hot water or steam pipes are used, the air can only be moderately

warmed ; and as the ascensional force in such case is not great, the ventilating openings can be placed at any desired point.

This plan of placing the ventilating openings near the floor is also recommended, on the score of economy. For, as the ventilating power can only be obtained at the expense of the heating power, much of the heat used to warm the room must be lost, if the ventilating openings be placed in the ceiling. So, also, if the temperature be moderate, the products of combustion and respiration may be cooled, and thus deprived of their ascentional force before they have time to escape by the ventilator.

In the warming of a building, by Mr. Perkins's system of one inch tubes, a forcing power is produced in procuring ventilation, and the openings for the purpose can be placed at any convenient point, either singly near the floor, or in conjunction with a second opening at the ceiling. "In the ventilation and warming of a private dwelling, I would begin, first," says Mr. Richardson, "with the staircase. This we ought to consider the principal artery of the house; and if this were well warmed by a current of warm fresh air flowing into it, and a constant change effected by a ventilating outlet, warmed, so as to ensure its effective operation, great part of the business would be effected, as the staircase would supply all rooms not in use with warm air in a sufficient degree, and would gradually ventilate the whole building, rendering it unnecessary to have further ventilation, except in the principal living and sleeping rooms of the family." But every room in the house might be ventilated, by placing two or more spare columns of tubing in flues concealed within the thickness of the wall. It will be seen, by reference to Fig. 57, p. 150, that where the flue passes in its course through two or more stories of small rooms, a small opening, about six inches square, made from each room into the flue, would, if provided with a proper outlet at the top, effectually ventilate every room. The flue should, of course, be vertical, and enclose the expansion tube at the top, where it should terminate in a tin funnel

provided with a turn-cap, to prevent downward currents of air. As soon as the fire was lighted in the furnace below, all these openings into the flues would become so many artificial fire places, drawing from the room a constant current of cooler air into the flue, which, being warmed to a very high temperature by the great quantity of pipe within it, the current of warm air would rapidly ascend into the open air above; thus affording all the advantages of constant spontaneous ventilation. In summer, when the warming effects of this system are seldom wanted, the circulation may be turned off from all the rooms by the stop-cocks, and the effects of the hot pipes be confined within the flues. The ventilation would then be carried on as usual, and no additional warmth be experienced from the action of the pipes. The advantages of this arrangement for our changeable climate are obvious, for on a cold day in summer, the stop-cocks being opened, the circulation would proceed through the coils in the rooms, and thus raise the temperature as desired.

Thus it will be seen, that by having a flue of the whole height of the building for the reception of the hot water tubes, the vitiated air can be drawn out of the room at any point. By means of the lower opening, the temperature of the room is equalized, and the effects of currents of unequally mixed air removed or mitigated; while the upper opening carries off the effluvia of the room. The openings should all be furnished with slides, so that they may be contracted or enlarged at pleasure.

In large public rooms, the size of the ventilating openings ought to be accurately determined by the architect. They ought to be large enough to allow every person in a crowded room to have a proper supply of air for healthy respiration. In a less crowded state of the room, the openings may be diminished by means of slides. By increasing the temperature in the flues, their ventilating power is, of course, increased, and this may be done by arranging a coil within the flue at each opening.

In connection with this system of warming and ventilating, is a plan, which, at first view, appears to be strange and unnatural; namely, that by which the fresh warmed air is admitted into the room by openings near the ceiling, and the vitiated air drawn out through openings near the floor. The advantages of this plan, as contrasted with upward ventilation, are stated to be these:—with upward ventilation, a great part of the vitiated atmosphere of crowded rooms is liable, by the slightest check or condensation, to be thrown down and mixed with the air, which is already partly unfitted for the purposes of respiration. But let the ventilating current descend, we have a bright atmosphere of pure air, which, as it becomes contaminated by respiration, is drawn downwards and discharged. On the other hand, this method of ventilation by descent has been denounced as a "noxious fallacy," because the vitiated air from the lungs having a temperature of 98°, naturally rises through the air of the room, which is of the temperature of 60° or under; and, if forced downwards by any means, must be breathed over again by the occupants of the room, before it can be discharged at the level of their legs and feet, in opposition to the laws of gravity. There is much truth in this objection, and we do not see how it is to be answered, unless the velocity of the outgoing current be so considerable as to amount to a strong wind; and it is, or ought to be, the object of all ventilation, to prevent the motion either of the incoming or outgoing current from being felt. This plan of ventilation by descent has been put into operation at the Model Prison, at Pentonville, where the solitary system of discipline is enforced, thus giving rise to the necessity of having a separate cell for each prisoner. In each cell the windows are fixtures, and the doors are effectually closed, so that the only mode of introducing the requisite supply of fresh, and of abstracting the vitiated air, must be by artificial means. The objection to applying ordinary modes of ventilation, by opening windows or by similar means, is the facility such openings give to the transmission of sound.

The method by which this descending ventilating current is produced, is compared by Major Jebb* to the ventilation of a coal-pit, in which, as already explained, the fresh air entering the down-cast shaft, passes through the numerous galleries and workings of the mine, and escapes by the up-cast shaft, the ventilating force consisting of a large fire in the up-cast shaft. In applying such a system to the ventilation of a prison, the objects proposed to be attained were, 1st, The regular supply of a sufficient quantity of fresh air, and, when necessary, of warmed air into each cell, without subjecting the occupant to any inconvenience from the draught. 2nd, The withdrawal of a like quantity of vitiated air. 3rd, That no additional facilities of communication between prisoners in adjoining cells should be afforded by the means made use of, and, therefore, that the transmission of sound be carefully guarded against. The reader who wishes to inspect all the details of the arrangements by which these objects are carried out, is referred to Major Jebb's paper, and the copious series of engravings by which it is illustrated; but a general idea of this method may be conveyed by the following remarks, to any one who has studied the various methods of warming and ventilating as described in this little volume.

In the basement story is a case or boiler, with a proportion of pipes adapted to the circulation of hot water, and in connection therewith, is a large cold air flue open to the outer air, for supplying air to be warmed in passing over the boiler and pipes. This air then passes right and left along a horizontal flue, under the floor of the corridor of the prison; and from this flue, a communication is established by small lateral flues with each cell, both on the lower and two upper floors, each small flue terminating in a grating under the arched ceiling of each cell. "The object of making the point of entry at the

* *On Modern Prisons: their Construction and Ventilation.* By J. Jebb, Major Royal Engineers, Surveyor-General of Prisons. With ten plates, 4to.. Published separately from "Papers on subjects connected with the duties of the Corps of Royal Engineers." Vol. VII. London, 1844.

top of the cell instead of at the bottom, and diffusing it through a grating on an extended surface, is, that no unpleasant draught may be experienced by the occupier of the cell, which, in a confined situation, would be the case, were it brought in at the level of the floor; and that he may not have any inducement to frustrate the intention of ventilation, by stopping it up." A corresponding quantity of foul air is extracted by means of a grating placed close to the floor of each cell, diagonally opposite the opening by which the fresh air is introduced. This grating covers a flue which passes up the outer wall, and communicates with a main foul-air flue placed in the roof, and terminating in a ventilating shaft rising above the top of the building. By this arrangement, the total lengths of each pair of flues respectively used for introducing fresh air into the cells, and extracting foul air from them, are rendered nearly equal on all the stories. This promotes uniformity of action; and the advantage due to the ascending system, and to difference both of temperature and altitude, is also secured. "Another provision of some importance should be adverted to. Fresh air should be taken into the main flues, communicating with all the cells in the respective wings or divisions, from the side which happens to be exposed to the wind. The force or pressure produced by a very moderate breeze, combined with the other arrangements and circumstances which are favourable for ventilation, will generally cause a sufficient current to pass through the cells without any fire being lighted in the extracting shaft for ensuring it. The operation of the system will, by these means, at all times be improved, and a considerable saving of fuel will be effected." The same flues are used for ventilating the cells both in winter and in summer; the only difference between the arrangements of the two seasons being, that during the summer, when air is introduced into the cells at its natural temperature, a fire is lighted when necessary in the ventilating shaft; during winter, when the temperature of the air must be raised, a fire is lighted in the heating apparatus below, the

smoke and disposable heat from which being discharged into the shaft, answer the same purpose.

It has been shewn, by experiment, in the Pentonville Prison, 1st, That from 30 to 45 cubic feet of pure fresh air is made to pass into every cell in a minute, and that this abundant ventilation goes on with great regularity. 2nd, That this current of ventilation, and a temperature of from 52° to 60°, can be uniformly maintained in the cells during the coldest weather, at an expense of less than one farthing per cell for twenty-four hours, and the summer ventilation, by means of a fire lighted in the extracting shaft, has been kept up at less than half the expense.

We come now to notice an application of steam to the purposes of ventilation, which is, in all respects, peculiar. It was remarked, nearly fifty years ago, by Dr. Thomas Young, that whenever any elastic fluid is forced from a jet with a very small velocity, the stream proceeded for many inches without any observable dilatation, and then diverged at a considerable angle into a cone, and, at the point of divergency, there was an audible and even a visible vibration. When the pressure is increased, the apex of the cone approaches nearer to the orifice of the tube, but no degree of pressure seems materially to alter its ultimate divergency. The distance of the apex from the orifice is not proportional to the diameter of the current; it appears rather to be the greater the smaller the current, and is much better defined in a small current than in a large one. Popular illustrations of this curious fact may be seen every day. A puff of smoke from a factory chimney, on being first shot out, may often be seen to assume the form of a ring, the diameter of which does not greatly exceed that of the chimney, but as it ascends in a still atmosphere, it gradually increases in size. In the firing of ordnance on a calm day, these rings may be seen on a grand scale, and still more perfectly if the mouth of the cannon be greased, and no shot used. The same phenomena may also be observed, on a small scale, in the smoke of tobacco projected from the mouth of a

skilful smoker. The rotating clouds of smoke from the chimney of a steam-boat, have also a tendency to form these conical rings, but from its abundance and the motion of the vessel, the form is not very defined. But the rings of smoke produced by the combustion of bubbles of phosphuretted hydrogen, shew the structure and motion of these rings very admirably. These hollow rings are seen to revolve on the axis of the cylinder from which they are projected, and gradually expand on rising into the air: each of these enlarging rings may be viewed as a magnified element of the cone issuing from the jet in Dr. Young's experiment.

It was further observed by Dr. Young, that the stream of air, projected from an orifice, drew into its current light bodies near it, which were free to move. This lateral communication of motion in a fluid stream, was noticed in water by Venturi. This attractive force seems to arise "from the relative situation of the particles of the fluid in the line of the current with respect to that of the particles in the contiguous strata, which, whatever may be the supposed order of the single particles with respect to each other, must naturally lead to a communication of motion nearly in a parallel direction, and this may properly be termed friction. The lateral pressure which urges the flame of a candle towards the stream of air from a blow-pipe, is probably exactly similar to that pressure which causes the inflection of a current of air near an obstacle. Mark the dimple which a slender stream of air makes on the surface of water; bring a convex body into contact with the side of the stream, and the place of the dimple will immediately shew that the current is inflected towards the body; and if the body be at liberty to move in every direction, it will be urged towards the current in the same manner as in Venturi's experiment, a fluid was forced up a tube inserted into the side of a pipe through which water was flowing. A similar interposition of an obstacle in the course of the wind, is probably often the cause of smoky chimneys."

If, instead of the jet of air used in these experiments, we

employ a jet of steam, produced under a pressure of 32lbs., to the square inch, the attractive power is very considerable. The steam, as it escapes from the boiler, forms a cone, as in Dr. Young's experiments; and the quantity of air set in motion is equal to 217 times the bulk of the cone of steam. The force with which the particles of air surrounding this cone are drawn towards it, were illustrated by Dr. Faraday in a lecture at the Royal Institution, in various striking experiments. Hollow balls of one and two inches diameter were drawn into the cone, and sustained floating in the line of its axis even when, by an arrangement of the apparatus, the axis was thrown 35° out of the perpendicular. An upright glass tube, 18 inches long and 1 inch diameter, having one extremity plunged in water, and the other drawn into a capillary jet, was immediately exhausted of its contained air, the water being drawn up from the end of the tube, when the capillary jet was placed within the indraught of air occasioned by the cone of steam. By surrounding this cone of steam with a cylindrical jacket, the effects were still more remarkable in increasing the draught power of the jet. The air within the jacket is expelled, and a partial vacuum produced, whereby the air rushes in to supply the vacant space, sweeping before it, in its current, any light bodies, such as paper shavings, hollow balls, &c., and projecting them with considerable force from the top of the jacket.*

* It was shewn, many years ago, by Clement Desormes, that when steam, under high pressure, is allowed to escape from an orifice pierced in a plate, or the flat side of a boiler, and a flat disc is brought close to this plate, the disc is powerfully attracted to the plate. In this case, the elastic force of the steam issuing from the jet, and which tends to separate the plate and disc, diminishes rapidly in its course from the centre to the edges of the disc; at the same time, the radial currents, by their indraught, bring the two plates together with a power which is so much greater than the former, that the two surfaces adhere.

This experiment may be shewn in a popular manner by the following contrivance:—Cut a couple of cards each into a disc of about two inches in diameter, and perforate one of them at the centre, and fix it on the top of a tube, such as the barrel of a common quill; then give the

In the arrangements made by Mr. Barry for ventilating the House of Lords, this jacket forms the ventilating shaft, and its value will be seen from the following sketch of the general arrang ments for warming and ventilating the House, as gathered from a lecture by Dr. Faraday at the Royal Institution, on the 26th March, 1847, and reported in the *Athenæum.*

Mr. Barry's plan has been applied to the royal ante-chamber, the House of Peers, and the public lobby. It consists, first, in causing a current of air of regulated temperature to pass beneath the impervious floor of these apartments, and afterwards to rise to a chamber at the top of the building, from whence it is diffused in great abundance, but imperceptibly, throughout the three apartments; and secondly, in drawing off the vitiated air, and discharging it with great rapidity into the atmosphere. To accomplish these objects, methods have been contrived for—1st, Warming the building through an impervious floor, as in the case of a Roman bath. 2nd, Effecting a system of currents. 3rd, Providing means for causing 10,000 cubic feet of air per minute to proceed on a prescribed course and regulated velocity. 1st, As to the mode of warming: a steam cockle, supplied from one of Lord Dundonald's boilers, is traversed by a quantity of air tubes firmly fastened into it. The air which passes through these tubes, is the source of warmth. This apparatus, with its furnace, is placed beneath the public lobby, and the current of warm air passes beneath its impervious floor, then beneath that of the House of Peers, and, lastly, beneath the floor of the royal ante-chamber beyond.

other card a slight bend, and place it over the first, with the convexity upwards, so that the orifice of the tube may be directly under and almost in contact with the upper card; hold the two cards horizontally, and blow through the tube, it will be found impossible to blow off the upper card.

The attractive force of the blast of air may also be shewn by placing the upper card upon the table with its concave surface upwards: then bring the other card immediately over it, and blow through the tube; the card will start up from the table and adhere to the other, so long as the blast is sustained.

With warmth, the air acquires a certain degree of motive power in the rising parts of the passages, which carries it onward till it reaches the reservoir chambers at the summit of the building; from thence it is made to pass down into the apartments by their walls, and so distributed, without draught, to be breathed by the inmates of these rooms. This gradual diffusion of the air is accomplished by, 2nd, A system of currents, which are caused by subjecting the air to inequalities of temperature. Descending by the walls of the building, it is cooled by the windows, &c., and thus its velocity downwards is increased. Arriving at the level, at which it is at once heated and deteriorated by respiration, combustion, &c., the air again rises in the centre of the room, and passes through the ceiling into a foul air chamber, which is in connection with a chimney. Through this chimney, the air is driven by a steam jet, which, as already stated, will set in motion 217 times its own bulk of air. It was shewn by Dr. Faraday, in this lecture, how the steam cockle employed to give warmth in winter, might, by filling it with water from the Artesian well, become a source of coolness in summer. The advantages of Mr. Barry's method of ventilation are thus summed up. 1st, The prevention of local draughts. 2nd, The prevention of the stains and disfigurements resulting from such draughts. 3rd, The avoidance of all movement and dispersion of the dirt and dust of the house by currents occasioned in it, which currents, if existing, would tend to render the air impure. 4th, The avoidance of all sudden changes of temperature. Finally, it was noticed that all parts of the house were fire-proof, and that this scheme of ventilation was under a disadvantage, as it had to be adapted to buildings which were not planned with reference to it.

Objections have been made to the vacuum principle of ventilation, on the ground that the air within the room or building thus ventilated is rarer than that without, and that air, even slightly rarefied, occasions languor and uneasiness to persons who are not in robust health, whereas the opposite

condition, or condensed air, has a bracing effect both on the body and on the mind. Schemes have been proposed, at different times, for making air-tight rooms, in which air was to be pumped in or out, according to any degree of pressure adapted to the wants and feelings of the occupant. Thus Dr. Henshaw, in 1664, acting upon one of Mr. Boyle's speculations, proposed such a room "by which any person may receive the benefit of a removal to another climate, at any season of the year, without removal from his own house, or neglecting any employment whatever." This air-tight room was to be occupied two or three hours in the morning in chronical cases; but in acute diseases, the patient might remain in it during the whole course of the disease, as in intermittent fevers, in which case the air was to be rarefied in the cold fit, and condensed in the hot fit. We are not aware whether these fanciful speculations were ever put in practice, but the idea was revived some years ago by Mr. Vallance, who proposed to construct air-tight rooms, with an aperture in the ceiling for pumping in the air, and a peculiarly constructed door for admitting the occupants in and out. The doorway was 6 feet high, and 6 feet wide, and was fitted with a cylinder of wood, closed at both ends, and placed upright. In the side was an opening 4 feet wide, and on the opposite side, a similar opening. In the centre of this cylinder was a perpendicular revolving shaft, with four leaves, crossing at right angles, fitting the cylinder as closely as its revolving motion permitted, and yet preventing the escape of the air at the edges. When a person entered the room, he placed himself between two leaves, like a turnstile, and, in this way, interfered as little as possible with the enclosed air. A pipe was fixed to the aperture in the ceiling, and carried through the roof, where it was inserted a few inches into a cistern of water. Air was injected into the room by means of machinery. When the weather was warm, the injected air was cooled by being passed through pipes surrounded by cold water, and if heated air were required, the pipes were surrounded by hot water. As the

fresh air was pumped in, as much vitiated air was forced out at the pipe in the ceiling, and it escaped through the water in the cistern, which thus ingeniously regulated the pressure of the air in the apartment. When a room is thus filled with condensed air, its expansive force is exerted so that every crevice about it becomes a channel to let air out, instead of into it, and thus draughts are effectually prevented.*

The advantages of condensed air as a medium of ventilation have also been insisted on by competent authorities of our own days. It appears, from some experiments made on this subject by Dr. Junot, that "when a person is placed in condensed air, he breathes with increased facility; he feels as if the capacity of his lungs were enlarged; his respirations become deeper, and less frequent; he experiences, in the course of a short time, an agreeable glow in his chest, as if the pulmonary cells were becoming dilated with an elastic spirit, while the whole frame receives at each inspiration a fresh vital impulse. The functions of the brain get excited, the imagination becomes vivid, and the ideas flow with a delightful facility; digestion becomes more active, as after gentle exercise in the air, because the secreting organs participate immediately in the increased energy of the arterial system, and there is, therefore, no thirst."

Dr. Ure, in advocating the *plenum* method of ventilation,† gives a curious example of the effects of condensed air upon some workmen engaged in sinking a shaft to a great depth through the bed of the river Loire, near Languin. In this district, the seams of coal lie under a stratum of quicksand, from twenty to twenty-two yards thick, and they had been found inaccessible by all the modes of mining previously attempted. M. Triger, an able engineer, constructed a shaft, encased with strong tubing, formed of a series of large sheet iron cylinders, rivetted together. At the top of this cylinder

* Vallance, *Observations on Ventilation*, as quoted by Mr. Bernan.

† *Supplement to the Dictionary of Arts, Manufactures, and Mines.*

was an air-tight ante-chamber, into which air was condensed by forcing-pumps with sufficient force to repel the water from the bottom of the cylinder, and thus enable the workmen to excavate the gravel and stones to a great depth. The compartment at the top had a man-hole in its cover, and another in its floor. After the men had entered, they shut the door over their heads, and then turned the stop-cock of a pipe in connection with the condensed air in the under-shaft. An equilibrium of pressure was soon established in the ante-chamber by the influx of the dense air from below, whereby the man-hole in the floor could be readily opened to allow the men to descend. Here they worked in air maintained at a pressure of three atmospheres (or 45lbs. on the square inch) by the incessant action of leathern valved pumps, driven by a steam-engine. While the dense air thus expelled the waters of the quicksand out of the shaft, it infused such energy into the miners, that they could easily excavate double the work which they could do in the open air. Upon many of them the effects were painful, especially upon the ears and eyes, but before long they became quite reconciled to the bracing atmosphere. Old asthmatic men became effective workmen; deaf persons recovered their hearing; while others were sensible to the slightest whisper.* Much annoyance was at first experienced from the rapid combustion of the candles, but this was obviated by the substitution of flax for cotton in the wicks.

* Many years ago, Mr. Roebuck and another person allowed themselves to be shut up in a cavity excavated in a rock, which served as a reservoir of air for equalising the blast of the bellows in an iron foundry on the banks of the river Devon, near Alloa, in Scotland. As much as 9,300 cubic feet of air were injected per minute, under a pressure of five inches of mercury. It was found that sound was greatly magnified, "as we perceived when we talked to each other, or struck anything: particularly the noise of the air escaping at the blow-pipe, or waste valve, was very loud, and seemed to return back to us." There was, however, no wind to disturb the flame of a candle, neither was it blown out when it was placed in the eduction pipe of sixteen inches diameter, through which the air passed into the furnace.

In ventilating a building on the plenum method, Dr. Ure recommends that the air be thrown in by means of a fan situated in the basement story,* and instances the method adopted at the Reform Club House, where there is a large fan revolving rapidly in a cylindrical case, capable of throwing 11,000 cubic feet of air per minute into a spacious subterranean tunnel under the basement story. This fan is driven by a steam-engine of five-horse power. The steam of condensation of the engine supplies three cast-iron chests with the requisite heat for warming the whole of the building. Each of these chests is a cube of three feet externally, and is distributed internally into seven parallel cast-iron cases, each about three inches wide, which are separated by parallel alternate spaces of the same width, for the passage of the air transversely as it is impelled by the fan. "This arrangement," says Dr. Ure, "is most judicious, economising fuel to the utmost degree, because the steam of condensation which, in a Watts's engine, would be absorbed and carried off by the air-pump, is here turned to good account, in warming the air of ventilation during the winter months. Two hundred weight of fuel suffice for working this steam-engine during twelve hours. It pumps water for household purposes, raises the coals to the several apartments on the upper floors, and drives the fan ventilator. The air, in flowing rapidly through the series of cells, placed alternately between the steam-cases, cannot be scorched as it is generally with air-stoves; but it is heated only to the genial temperature of from 75° to 85° Fahr., and it thence enters a common chamber of brick-work in the basement story, from which it is let off into a series of distinct flues, governed by dialed valves or registers, whereby it is

* As powerful blasts of air are not required for the purposes of ventilation, a rapid movement of the fan is not necessary. Fans making 2,000 revolutions per minute are exceedingly disagreeable from the noise and vibration occasioned by them. Quantity of air, not velocity, is the object, and for this purpose, fans of ten or twelve feet diameter, moving slowly, are to be preferred.

conducted in regulated quantities to the several apartments of the building. I am of opinion that it would not be easy to devise a better plan for the purpose of warming and ventilating a large house." In the top story of the building is a large furnace, the draught of which is intended to draw off the air after it has served the purposes of warming and ventilation in the rooms below. Messrs. Easton and Amos are the contrivers of this system.

CONCLUSION.

We have now nearly reached the limit of the space allotted to us in this Rudimentary Treatise, and are anxious in the few remaining pages again to enforce the necessity of adopting an efficient system of ventilation in our rooms and public buildings. The arrangements for warming are, for the most part, beyond the control of individuals; these are settled by the house-builder or architect according to ancient rule, and are adapted to our feelings or prejudices in favour of open fire-places; but the ventilation of our rooms depends in great measure upon ourselves, and we may be fairly charged with a presumptuous neglect of natural laws, if we fail to make use of some of the simple means for obtaining ventilation which have been detailed in previous chapters. Before science had discovered the pernicious effects of impure air, it was not surprising that people did not ventilate. No plans for ventilation could be laid down on a proper basis, until the composition of the atmosphere had been properly defined: no definite meaning could be given to the word *ventilation*, until the nature of the air itself was known, and the products of respiration and combustion had been proved to be poisonous.* But no sooner had the beautiful

* Ventilation was probably first practised in mining districts, as a work of necessity, in consequence of the rapid conversion of the oxygen of the air into carbonic acid, by the respiration of the miners, the com-

experiments of Priestley, Cavendish, and others, made an impression on the scientific minds of the day, than means were contrived for ventilation. Thus Cavallo, in his *Treatise on the Nature and Properties of Air* (4to., London, 1781), quotes from an older work, a method of ventilating a room by means of a small tube opening into it, in or near the ceiling, which might either be carried to the top of the building, or be made to communicate with the external air by a small perforation through the wall at the roof the room, by means of either of which, a proper circulation would be established, and the foul air be carried off. In order to admit fresh air into the room, another opening was made in the ceiling, having a communication with a small pipe that led from thence to the outside of the wall, where it was bent and conducted downwards till it reached the ground, being left open to communicate with the external air. The cool air would thus be forced in at the lower opening of the tube, and made to ascend into the apartment in proportion to the quantity that escaped towards the higher regions, by means of the ventilator.

Here we have a plan of ventilation at least seventy years old, and yet, at the present day, ventilation is still discussed and quarrelled over, as if it were some new thing. The proper supply of fresh air is denied to the great mass of the population, because builders, who ought to be perfectly ac-

bustion of their candles, and the large quantities of irrespirable gases liberated by the gunpowder used in blasting. Mr. Henwood has given a summary of the analysis of eighteen samples of air taken from the mines of Cornwall and Devon, from which it appears, that the proportion of oxygen was only 17.067 per cent., while the carbonic acid was 0.085; the nitrogen 82.848; and in one instance, the proportion of oxygen was reduced to 14.51; and in another, the carbonic acid was 0.23 per cent. These results shew a diminution in the proportion of the vital ingredient of the atmosphere from its usual per centage of 21, and an increase of the poisonous ingredient, carbonic acid, from 0.05, its usual amount, calculated to produce great injury to persons exposed to the breathing of such a fluid for hours together.

quainted with these things, (who ought also to be able to construct chimneys that will discharge their smoke into the air instead of into the room), too often neglect to study the natural laws which chemists and physiologists have placed on a sure basis. We are told that the native porters of Canton are accustomed to balance the load which they carry on a pole upon their shoulders, by means of a large stone at the other extremity of the pole, and that they deemed the suggestion of an Englishman an impertinent interference, who wished them to balance one package by means of another. "Our ancestors," they said, "were very wise men, and they never carried more than one package at a time, and this they balanced by means of a stone; shall we be wiser than our ancestors?" So may a large proportion of our modern builders exclaim, "Our ancestors were very wise men; they never thought of providing special means for ventilation in rooms and public buildings; shall we be wiser than our ancestors?" Many a powerful satire on the modern practice of house-building is afforded by the stifling effects of ordinary dwellings. For example, Dr. Macculloch, in his *Account of the Hebrides*, remarks, that while the inhabitants had no shelter but huts of the most simple construction, which afforded free passage for currents of air, they were not subject to fevers; but when, through the good intentions of the proprietors, new dwellings were erected, and were made *close*, *comfortable*, and *commodious*, the stagnating air, and other impurities, joined to the want of cleanliness in the inmates, generated febrile infection. Now, we think, it must be admitted, that had these new dwellings been properly ventilated, by special means contrived for the purpose, there is no reason why they should have been more unhealthy than the old ones.

When the great masses of the population become fully alive to the necessity of abundant supplies of wholesome air within doors, then, and not till then, will they also become alive to other sanatory measures; then will every house be properly

supplied with pure water, efficient sewerage, and special means for letting out foul air and admitting fresh; then shall we cease to bury our dead in the midst of the living; then will cattle-markets, slaughter-houses, and all noxious trades, manufactures, and occupations, be removed to a greater distance from dwelling-houses; then shall we have boards of public health filled by competent men, and endowed with adequate powers; then will vested rights in injurious abuses yield to public opinion, and the health and well being of the population will be of paramount interest.

At the risk of repetition, let us consider the grounds which render a proper supply of pure air necessary to health. In the process of respiration, the blood, in passing through the lungs, is exposed to the action of the atmospheric air, during which exposure it undergoes certain changes. The blood from the right side of the heart, when it enters the lungs, is of a dark red colour; it is then dispersed in a state of most minute subdivision through the ultimate vessels of the lungs, and in these vessels is brought into contact with the atmospheric air, when it becomes of a bright red colour. In other words, the blood changes in the lungs its *venous* appearance, and assumes the character of *arterial* blood. The blood thus arterialized, returns to the left side of the heart, from whence it is propelled through the whole arteries of the body. In the minute terminations of the arteries, the blood again loses its florid hue, and, reassuming its dark red colour, is returned through the veins to the right side of the heart, to be exposed, as before, to the influence of the atmospheric air, and to undergo the same succession of changes.

On examining the respired air, it is found that a portion of its oxygen has disappeared, and a similar bulk of carbonic acid has been substituted. While oxygen gas is passing inwards through the membrane of the lungs, carbonic acid is at the same time passing outwards through the same membrane. In fact, the oxygen of the air is absorbed by the blood, and in some unknown state of combination, reaches the extreme

subdivision of the arteries, where it is united with a portion of carbon, and forms carbonic acid gas, which gas also, in some unknown state of combination, is retained in the venous blood, till in the lungs it is expelled, and oxygen is absorbed in its stead. Along with the carbonic acid, a large quantity of aqueous vapour is at the same time separated from the blood.

One great object of this process is the production and maintenance of animal heat. From a comparison made by Professor Miller, of King's College, of the results of numerous experiments, it appears that a man of ordinary stature consumes, in the course of 24 hours, 9 ounces (Troy) of carbon; that the heat generated during the combustion is sufficient to boil away 8lbs. of water; that the consumption of oxygen in this process is equal to 24 ounces, or 19.4 cubic feet; that the quantity of air vitiated amounts to 97.2 cubic feet; and the product in carbonic acid, to 33 ounces.

These results are, of course, liable to much variation in the same individual at different times, in different individuals, and in different sexes. The quantity of aqueous vapour is also liable to much variation, but the average quantity has been stated to be 3 grains per minute. We have seen that the carbonic acid is a deadly poison, and the water thus given off is not pure water, such as is liberated in the process of distillation or evaporation, but is contaminated with the most offensive animal effluvia. M. Leblanc states, that the odour of the air at the top of the ventilator of a crowded room is of so noxious a character, that it is dangerous to be exposed to it even for a short time. If this air be passed through pure water, the water soon exhibits all the phenomena of putrefactive fermentation. The water of respiration thus loaded with animal impurities, condenses in the inner walls of buildings, and trickles down in fœtid streams. In the close and confined dwellings of the poor, this vapour condenses on the walls, the ceiling, and the furniture, and gives that permanently loathsome odour which must be familiar to all who take sufficient interest in the poor of large towns ever to

enter their dwellings. Take up a chair, and it is clammy to the touch, and the hand retains the ill odour; and, if the poor people are remonstrated with, on the ground of want of cleanliness, they say that the supply of water is scanty, and what little they have, must be dragged upstairs from the yard or cellar below. The low state of health induced by such abodes produces a chilly sensation, even in summer, which renders the occupants averse to open windows, and, in many cases, in consequence of the crowded state of some burial grounds, and the fœtid odours emitted from the sewer traps in the streets, an open window is a questionable remedy for bad ventilation.

We see, then, that there are many causes which render respired air injurious, if made to enter the lungs a second time. In proportion as the air of a confined space becomes vitiated by respiration, the quantity of carbonic acid increases, and as chemistry furnishes the means of determining this increase, while the other noxious products of respiration escape from exact analysis, the amount of carbonic acid may be taken as the exponent of the degree of vitiation of the confined air. This method was adopted a few years ago, by M. Félix Leblanc, in an extensive series of experiments.*

In conclusion, the writer wishes to state, that if the inventor of any patent warming or ventilating apparatus feels himself neglected in these pages, he may be assured that the omission arises either from want of space, or from want of novelty in the essential details of the invention. It is no compliment to the inventive genius of the present day, to be compelled to state that many of the contrivances, especially for warming, which are put forth as new, and even patented, do not differ in principle from some of those described in old treatises, several of which have been referred to in this work.

C. T.

Bedford-place, Ampthill-square,
June, 1850.

* See Memoir read to the Academy of Sciences at Paris, 6th June, 1842, and inserted in the *Annales de Chimie et de Physique*. Third Series, vol. v. p. 223.

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XIV. Observations on the Effect of Old London Bridge on the Tides, &c.
2. Professor Farish on Isometrical Perspective.
3.
4.